Ministry of Higher Education & Scientific Research
Ninevah University
College of Electronics Engineering
Communication Engineering Department

Design and Performance Investigation of Cognitive Radio (CR) Based Non-Orthogonal Multiple Access (NOMA) for the Next Generation of Wireless Communications

By

Ahmad Abd Saeed Sultan

M.Sc. Thesis

In

Communication Engineering

Supervised by

Dr. Mohamad Abdulrahman Alhabbar

2022 A.D. **1444 A.H.**

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A Thesis Submitted

By

Ahmad Abd Saeed Sultan

To

The Council of the College of Electronic Engineering

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for the Degree of Master of Science

In

Communication Engineering

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2022 A.D. **1444 A.H.**

بسم الله الرحمن الرحيم

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سورة يوسف – اية 76

Supervisor's Certification

I certify that the dissertation entitled **"*Design and Performance Investigation of Cognitive Radio (CR) Based Non-Orthogonal Multiple Access (NOMA) for the Next Generation of Wireless Communications*"** were prepared by **Ahmed Abd Saeed** under my supervision at the Department of Communication Engineering, Ninevah University, as a partial requirement for the Master of Science Degree in Communication Engineering.

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Dedication

I dedicate this work to my parents, especially to my mother because she always prays for me to be successful in life, as well as to my wife, my children, my siblings, my friends, and especially to those who did not leave me until completed this work.

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First and foremost, praise be to thank the Almighty **Allah** for blessings and for giving me the strength to carry out and complete this work. May peace and blessings be upon the first teacher of humanity, Prophet **Muhammad.**

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Ahmed

Abstract

In this thesis, non-orthogonal multiple access (NOMA) is investigated and analyzed as a technique to enhance spectral Efficiency (SE). By utilizing NOMA two users and more can share the available spectrum simultaneously but with different power allocation factors in the power domain. The cognitive radio (CR) technique is used with NOMA to increase the SE, in which spectrum sensing is not required as suggested in this dissertation. Moreover, the key thing is satisfying the required quality of service (QoS) for the primary user (PU), with the best performance for the secondary user (SU). Three scenarios with different algorithms are proposed depending on a pairing algorithm that couples a PU with an SU in single pair depending on the required rate, the available power, and the distances of the users away from the source provider. CR based on NOMA is considered over frequency non-selective Rayleigh fading channels in the presence of additive white Gaussian noise (AWGN). Monte Carlo simulations using Matlab are employed to simulate the three scenarios, and the obtained results are compared with traditional CR-NOMA systems. The results demonstrate the outperforming of the PU against the SU in two performance metrics which are the outage probability and the achievable rate due to giving the priority to the PU to obtain its required QoS. For the considered scenarios, the PAF plays a significant role to keep the PU and SU in the best performance in the downlink phase, while in the uplink phase the PAF is not required as the effect of the path loss exponent plays this role. Furthermore, the CR-based NOMA technique with Multiple-input multiple-output (MIMO) is proposed for the sake of improving the achievable throughput and satisfying user fairness. Different scenarios are assumed in this dissertation to investigate the performance of CR-NOMA users. Moreover, pairing algorithms are proposed and applied to obtain the optimum throughputs and outage

probabilities, in which the algorithms are employed to select a PU with an SU to be coupled in single pair, depending on the required QoS and the location of each user from the BS, taking into account that any PU has the priority to reach its required throughput. Moreover, mathematical expressions have been derived for each case to evaluate the required power allocation factor and the achievable throughput for each user. Furthermore, the proposed algorithms show successful and satisfactory achievable rates and outage probabilities.

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LIST OF ABBREVIATIONS

Abbreviation	Name
5G	Fifth Generation
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BS	Base Station
CR	Cognitive Radio
D2D	Device to Device
DoF	Degree of Freedom
IoT	Internet Of Things
LOS	Line of Sight
IA	Iterative Algorithm
MIMO	Multiple Input and Multiple Output
MISO	Multiple Input and Single Output
MIMO	Multiple Input and Multiple Output
MU	Multi-User
NOMA	Non Orthogonal Multiple Access
OMA	Orthogonal Multiple Access
OFDMA	Orthogonal Frequency Division Multiple Access
PAF	Power Allocation Factor
PU	Primary User
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
QAM	Quadrature Amplitude Modulation
Rx	Receiver
RSD	Road Side Unit
SIMO	Single Input and Multiple Output
SINR	Signal to Interference plus Noise Ratio

SIC	Successive Interference Cancelation
SU	Secondary User
SNR	Signal-to-Noise Ratio
SWIPT	Simultaneously Wireless Information and Power Transfer
Tx	Transmitter
U	User
V2X	Vehicle To Everything
ZFBF	Zero Forcing Beam Forming

LIST OF SYMBOLS

Symbol	Name
H	Channel Coefficient
$\boldsymbol{\beta}$	Path loss Exponent
P	Available Power at the Transmitter
B	System Bandwidth
R	System Throughput
PAF	Power Allocation Factor
$\boldsymbol{\sigma^2}$	Variance of Noise
D	Distance from Base Station to the User
Ω	Signal-to-Noise Ratio
W	Additive White Gaussian Noise
SE	Spectral Efficiency

CHAPTER ONE

INTRODUCTION

1.1 Preface

wireless communications expanded and entered all aspects of human life, which led to continuous development and qualitative leaps in the world of communications. One aspect of the challenge is the spectrum scarcity and the provision of communication to a huge number of users and the provision of high reliability and high data speed. The fifth generation (5G) of wireless networks, like the generations before it, emerged due to the pressing demand for more services. NOMA can achieve these purposes [1][2]. NOMA can play a vital role in satisfying massive connectivity by sharing the available power among several users in the cell via exploiting simultaneously the same frequency band. In the transmission with a BS in the uplink and downlink phases, NOMA can satisfy user fairness, secure connectivity, and SE by applying the power allocation method. The latter technique can be achieved by giving the furthest users from the BS, i.e. the users with low SNR. More portion of the available power than the users near BS. The SIC model is applied to each user in the NOMA system, except the furthest user from the source, by detecting the signal of the higher-order user followed by implanting a subtraction from the entire incoming NOMA signal to obtain the signal of interest for that user. It is interesting to mention that the furthest user, which has the highest portion of the power can detect its signal without the need to apply the SIC [1][3]. Some study refers that there will be millions of devices in $(1\ \mathrm{k}m^2)$ which is considered a large number of devices that leads to spectral scarcity [4].

The CR technique is one of the efficient techniques that can be utilized to solve spectral scarcity by serving one or several secondary users in the presence of a primary user, on the same frequency band, and without affecting the required throughput rate in (bit/sec/Hz) of this main user in the network [5]. In other words, the (SU)s can utilize the available spectrum in case of the presence or absence of the PU by applying optimization techniques to keep the target throughput of the PU at its required level [6]. Most of the previous states of the arts utilize spectrum sensing to allow the secondary user to access the CR system, which means that there is a specific time to achieve this sensing which means there is a delay time, additionally, the secondary user will not be able to remain in the same spectrum resource for a long time. NOMA solves these issues, which are inherent with CR, by controlling the rates of all users via the Power Allocation Factor (PAF) and pairing algorithm. Giving each user the necessary power in NOMA based on their channel coefficient is crucial to achieving fairness and high-quality service. Furthermore, selecting a user to be paired with another one in NOMA systems, that uses MIMO, is essential to maximizing spectral efficiency (SE) [7]. Moreover, by using joint user pairing and dynamic power allocation, downlink NOMA-MIMO can maximize energy efficiency [8]. In NOMA, power is allocated to each user as required; however, in cognitive radio, there is a condition that the (SU)s could use resource allocation for the PU as long as the PU QoS is guaranteed. Additionally, CR networks are the face of NOMA, and they are used to increase the quality of service and improve spectrum efficiency [9].

1.2 Literature Review

In 2013 Yuya Saito et al. presented a System-Level Performance Evaluation of Downlink NOMA. In addition to NOMA's specific features, such as dynamic multi-user power allocation, they demonstrated that NOMA's total cell throughput, cell-edge user throughput, and proportional fairness are all superior to OMA's [10].

In 2013, Anass Benjebbour et al. discussed the concept and practical considerations of non-orthogonal multiple access (NOMA) with a SIC at the receiver side. They discussed how to combine NOMA and MIMO by using random beamforming to convert a MIMO channel into a single-input multi-output (SIMO) channel with a SIC receiver for intra-beam interference mitigation and an interference rejection combining (IRC) receiver for inter-beam interference mitigation [11].

In 2014, Zhiguo Ding et al. introduced that the intended data rates and power allocation that are allocated to the users have a significant impact on NOMA's outage performance. A wrong selection of the assigned power and targeted data rates, in particular, may increase the likelihood that a user may experience an outage. When it comes to ergodic sum rates, NOMA performs better than other methods [12]. Xinchen Zhang and Martin Haenggi presented the performance of successive-interference cancelation and when the SIC is beneficial in the network [13].

In 2015, in terms of fundamental ideas, significant traits, receiver complexity, and engineering viability, Linglong Dai et al. studied and assessed many of the leading 5G NOMA systems. In contrast to classic OMA, NOMA enables regulated interferences to produce overloading at the cost of a fair increase in receiver complexity. Because of this, NOMA can only partially meet the requirements for 5G's high spectrum efficiency and massive connection [14].

Zhiguo Ding et al. studied cooperative non-Orthogonal multiple access in 5G Systems. A key component of NOMA is that users with better channel conditions have prior knowledge of other users' communications. This letter's cooperative NOMA technique proposal heavily draws on this understanding. The outage probability and diversity order of this cooperative NOMA method are explored, and a user pairing-based strategy is proposed to lessen system complexity [15]. Jung-Bin Kim and In-Ho Lee presented non-orthogonal multiple access in Coordinated Direct and Relay Transmission (CDRT). The main problem of non-orthogonal (CDRT) can be overcome by utilizing NOMA's inherent trait of allowing a receiver to collect side information, such as data from other users' equipment, for interference cancellation. Analytical expressions for outage probability and ergodic sum capacity are provided for two user equipment [16].

In 2015, Shimei Liu et al. studied the NOMA-based downlink multi-user beamforming system, in which the BS tries to broadcast data to several user clusters at the same time, with each beam serving one cluster of two users. They also provided a user power schedule technique to ensure the proposed NOMA downlink multi-user beam forming system's advantages. According to simulation results, the suggested user selection algorithm and power schedule scheme can improve the sum rate of a NOMA-based downlink multi-user system, [17].

In 2016 Pongsatorn Sedtheetorn and Tatcha Chulajata reported a unique analysis of the non-orthogonal multiple access (NOMA) downlink spectral efficiency in a Rayleigh fading environment. they proposed a closed-form expression of NOMA spectral efficiency. The random-distributed system model is initially examined by using an accurate approximation technique. By simulation, they validated closed form, which helps them to identify the exact average of NOMA spectral efficiency at various system parameters, such as SNRs and user power allocations [18].

In 2016, according to Lei, the system performance in terms of throughput and fairness was improved by logically articulating NOMA resource allocation problems and utilizing algorithmic solutions to jointly optimize power and channel allocation in NOMA [19]. Also, Han Zhang et al. stated that by employing the user pairing algorithm method, more than one user with the same resources can be selected. This algorithm selects users with different channel conditions to achieve maximum capacity and user fairness [20].

In 2017 Faramarz Ajami Khales and Ghosheh Abed Hodtani wrote that the classification of users in (NOMA) is based on power, while it is based on time, frequency, and code in orthogonal multiple access. They studied the downlink NOMA that includes two users, one with strong power and one with weak power. The comparison of NOMA and OMA properties reveals a wide range of power allocation factors (PAF)s for the two users, with NOMA properties outperforming OMA. They obtained that in comparison to OMA the coverage zone of NOMA for both weak and strong users has increased, according to theoretical and analytical conclusions [21].

In 2017, Faeik Al Rabee et al. concentrated on power-domain NOMA. Successive Interference Cancellation (SIC) is employed at the receiver. For any number of transmitters, the optimum received power level for uplink power-domain NOMA with ideal SIC reception is calculated by using a formula. The obtained results showed that as the number of transmitters N increases, the optimum received power level increases linearly (in dB) and the maximum needed received SINR increases exponentially (or equivalently, linearly in dB). The optimum power levels are extremely comparable to those of the μ-law encoding used in Pulse Code Modulation (PCM) speech processors, which is an intriguing discovery [22]. Xiaolu Wang et al. wrote that NOMA is a popular multiple-access approach for achieving the best system capacity. They provided the exact closed-form BER expressions of the QPSK constellation for an uplink NOMA system over an additive white Gaussian noise (AWGN) channel, the validity of the resulting phrases is confirmed by simulation results. The QPSK BER expressions can be easily extended to the BER expressions in various fading instances with or without diversity reception since they are expressed as a sum of Q functions [23].

In 2017, a capacity-based user selection (CUS) algorithm for NOMA has been proposed by Abdelsalam Sayed et al. for a multiuser multiple input single output (MISO) downlink NOMA system with zero-forcing beam forming [27]. In this research article, choosing users for each cluster based on the improvement in the system's sum rate, by using the NOMA-CUS approach, achieved significant improvement in the NOMA system's sum rate. The methodology greatly improves performance over the previous methods, especially in system sum rate and average matched user rate, and achieves performance that is extremely near to the exhaustive search clustering formation [24]. Di Zhang et al. presented a merging NOMA with multiple-input multiple-output (MIMO) as one of the interesting strategies for increasing the overall system spectral efficiency and capacity [25]. Liang et al. made the case that the cluster's paired users receive electricity from the base station (BS). A user with low channel conditions is paired with a user who has good channel conditions when both users' rate needs are satisfied in the network. Additionally, by employing NOMA in CR to handle the power allocation and user pairing issues, as well as by utilizing distributed matching algorithm theory, the CR-NOMA system can outperform the OMA system with a significant performance advantage and a low implementation complexity. The PUs trades the available power with the SUs through negotiations of the power allocation coefficients, ensuring that both satisfy the necessary rate. [26].

In 2018 Ge Wang et al. analyzed and discussed that the receiver signal is distorted as a result of multiple access in NOMA. The parallel interference cancellation (PIC) technology is used with the NOMA system to address the issue of high delay and error propagation in the sequential interference cancellation (SIC) technique. Although it is very sophisticated, PIC can successfully make up for the deficiencies of the SIC algorithm. The advantages of SIC and PIC are combined in the proposed joint-interference cancellation (JIC) technique. Performance and complexity comparisons between the three algorithms are made. The results show that JIC can successfully reduce latency and address the issue of error propagation in low-complexity situations [27].

In 2018, Yuhao Chi et al. presented a practical MIMO-NOMA with low complexity along with a capacity-approaching solution. It can handle a variety of problems, including massive connections, minimal latency, and high reliability. The proposed coded MIMO-NOMA system accomplishes asymptotic outcomes within $(0-2)$ dB of theoretical capacity as a result of their findings [28].

In 2018, Esam et al. presented that the cumulative rate is maximized by combining both orthogonal multiple access (OMA) and NOMA techniques. Each pair of users is assigned by using traditional OMA, and every pair is paired by using NOMA [29].

In 2019 Zihan Tang et al. constructed a closed-form equation that encapsulates the whole NOMA outage attainable rate range, presented a sequential interference cancelation (SIC) order and discussed the NOMA outage. They also provided evidence for why NOMA should be used in this situation by demonstrating how NOMA performs better than OMA in terms of the outage reachable rate area [30]. In 2019, Selvam and Kumar contrasted the energy and spectrum efficiency trade-offs of the NOMA system's performance with those of a standard OFDMA system. They found that, for lower system bandwidth values, the NOMA system had much-improved spectrum and energy efficiency, making it more appropriate for machine-to-machine (M2M) communications. It can therefore offer a great platform for a variety of Machine-to-Machine communication devices [31]. MA. Ahmed et al. presented that it could get secure connectivity, users fairness, and high spectral efficiency for multi-users with different channel conditions by applying the PAF mechanism to give each user its required power and SIC at the receiver, and they studied outage probability and BER under different cases [32].

In 2019, Farid T.Miandoab and Behzad M. Tazehkand presented that the utilizing effective beam forming and the user pairing strategy for MIMO-NOMA, a near user can be coupled with two far users who have similar channel gains and non-overlapping frequency bands to achieve enormous connection, increase the individual rate of poorest users in each cluster, and prevent interference in the NOMA system [33]. In addition, Yu Sing Xiao and Danny H.K. Tsang had written that the interference from the secondary network and inter-cluster interference between the NOMA pairs can be removed by using a new interference alignment (IA) based on Coordinated Beamforming (CBF), in addition to allocating the power for cognitive MIMO-NOMA downlink networks (IA-CBF) [34]. In another work, the outage probability is defined by Zhiqiang Wei as the probability of the signal-to-interference plus noise ratio (SINR) that goes below a threshold SINR [1], or the probability that the throughput goes below a threshold rate for a particular user or the entire system [12]. Additionally, the achievable throughput is the capacity or the rate of the system in the presence of noise and interference circumstances over a specific transmission bandwidth as defined by Shannon [35].

In 2020, Santosh Babu et al. presented that the NOMA can be merged with CR in which two models of detection modes can be applied, primary first detection mode (PFDM) and secondary first detection mode (SFDM) to optimize problems of spectrum resource, the outage probability and throughput for the secondary user of CR is provided by using NOMA and a full-duplex relay [36]. In addition, the combination of an orbital angular momentum (OAM) based MIMO-NOMA is proposed by Ahmed Al Amin and Soo Young Shin. This is to improve the user and sum channel capacities of the downlink NOMA for multiple users. The suggested NOMA-OAM-MIMO method with the proposed number of the non-coaxial uniform circular arrays provides a much larger channel capacity than standard schemes by combining higher numbers of OAM modes [37].

In 2020, Tamanna Yasrab and Sanjeev Gurugopinath had written that by utilizing multipath propagation, MIMO employs several antennas in transmission and reception to boost radio connection capacity, a comparison of MIMO-NOMA-CR networks with a traditional MIMO-CR-based orthogonal multiple access (OMA), i.e. MIMO-OMA-CR networks, the average achievable throughput in the first networks is significantly higher than the latter, in which MIMO-OMA-CR requires a compulsory spectrum sensing which utilizes a technique of blind combined energy detection [38]. Additionally, Shuangli Wu et al. presented compressive sensing used with NOMA in which a compressed sensing-based linear predictor technique is employed to predict the traffic load at the next moment and forecast the traffic load and improve system performance [39]. Dinh-Thuan Do, et al. presented spectrum sensing and limited battery capacity at the roadside unit (RSU) may cause serious outage performance which is a key concern when implementing CR, where energy harvesting and RSU selection schemes benefit a system with SWIPT and a CR-enabled vehicle to everything based-NOMA (V2X-NOMA) network [40].

In another work, Salifou Mounchili and Soumaya Hamouda had written that the distributed-NOMA user pairing technique boosts low user pair's chances of achieving their best performance at the expense of other users' performance. Additionally, it shields them from the issue of zero channel gain difference and enables users of a specific NOMA set to achieve various throughputs more equitably [41]. Jue Wang et al. also suggested that for multiuser situations. In general, a location-based, straightforward user pairing strategy be used. The proposed user pairing algorithm can greatly speed up the rate at which resources are used when compared to the conventional multiple access and user pairing systems [42].

In 2021, Mohamed Hassan et al. had written that NOMA is one of the most promising techniques for the next generation of wireless communications in that it can improve spectrum efficiency significantly, while CR meets the tremendous demand for wireless connectivity by addressing the scarcity of spectrum. This can be achieved by implementing dynamic access and diversity over the entire available spectrum [43]. Shuangli Wu et al. had written that some strategies are being seen as promising trends for improving efficiency and reducing the complexity of 5G networks. They applied deep learning-based approaches, cooperative, compressive, and SWIPT sensing methods in NOMA, and MIMO-based CR among these techniques [44].In addition, Guangfu WuAs et al. presented that a CR-NOMA technology can serve more SUs by sharing the licensed spectrum with PUs, it can be considered one of the promising mechanisms to address the requirements of the internet-of-things (IoT) for enormous connections. In addition, energy efficiency has received considerable attention to extend extremely long battery life, particularly for energy-constrained IoT devices [45]. In another work, Mario Rodrigo et al. had written by leveraging simultaneous wireless information and power transfer, the rate-splitting multiple access (RSMA) framework in a multiuser (MU), based on multiple antenna transmission, is considered an essential part of CR systems, along with the power splitting of secondary users with PUs. The RSMA framework is a novel multiple-access technique based on linearly pre-coded rate splitting at the secondary base station and successive interference cancellation (SIC) at the secondary receivers. Its goal is to reduce the transmit power at the secondary service provider while adhering to restrictions on minimum energy harvesting, minimum data rate, and maximum power level for allowable interference with the PUs [46]. Furthermore, Nemalidinne Siva Mouni, et al. presented that an adaptive NOMA user pairing technique can achieve a trade-off in the user rates by coupling the strong and weak users, this is when the SIC is not ideal to optimize the total achievable sum rate (ASR) in a NOMA system. To guarantee NOMA rates, limitations on the fraction of power to be distributed among NOMA user pairs and the imperfect SIC have been calculated [47]. Moreover, Nibedita Nandan, et al. had written that a new transmit-zero-forcing beam forming (ZFBF) technique with signal alignment is suggested to enhance the physical layer security (PLS) to secure the communications in a multi-cell MIMO-NOMA based CR network system. This technique analyzes secrecy capacity and secrecy outage probability [48]. Kha-Hung Nguyen et al. investigated a joint optimization of NOMA beam forming and dynamic UE pairing in downlink access, which is a type of mixed-integer non-convex optimization issue. They derived an iterative algorithm based on relaxation and IA methods to solve the max-min rate problem. They Numerical results demonstrated that the proposed algorithm outperforms the existing methods[49]. Moreover, ISHAN BUDHIRAJA et al. offered a comprehensive overview of state-of-the-art NOMA variants in the 5G environment, using power and code domains as the backbone for interference mitigation, resource allocations, and QoS management. Device-to-device (D2D), cooperative communication (CC), multiple-input multiple-output (MIMO), and Heterogeneous Networks are all supporting future smart communication (HetNets). NOMA has been found to alleviate the majority of the concerns in existing ideas for providing contention-based grant-free transmissions between multiple devices. In 5G, the main contrasts between OMA and NOMA are also examined in depth [50]

1.3Aims and Objectives of the Study

1. Investigating the new trends (NOMA, CR, and MIMO) for the next generation of wireless communication that can enhance spectrum efficiency, satisfy user fairness, and increase the system throughput.
2. Studying the technique of NOMA, which is one of the most promising multiple access for MU wireless communications for the 5G and beyond-fifth-generation (B5G), to improve spectral efficiency and satisfy user fairness.
3. Merging NOMA with CR to improve the wireless system performance and utilizing the available spectrum to address the spectrum scarcity.
4. Designing pairing algorithms to create groups of two users and applying CR-NOMA within this each group to reduce the complexity of managing and processing several users in a traditional CR-NOMA.
5. Dealing with users and service providers, which are equipped with SISO and MIMO.
6. Introducing mathematical analysis for throughput evaluation of all scenarios which can be used for many investigative scenarios in wireless communications.

1.4 Layout of Thesis

This thesis is divided into five chapters. Chapter one presents the introduction and literature review. Chapter two explores the basics of NOMA and some techniques used with it, in which CR and MIMO can be merged with NOMA to improve the overall performance. In Chapter three, the pairing algorithms are introduced and employed to manage the merging of NOMA with CR for two users to communicate with the BS in the uplink and downlink modes, in which all the users and the BS are equipped with a single antenna. The effect of changing the distances with different PAF is taken into account in this chapter for evaluating the sum rate and the outage probabilities. Chapter Four investigates merging CR-NOMA with MIMO for the sake of improving the entire system's performance. In this chapter, three algorithms are considered to manage the transmission of multiple primary users (PU)s and secondary users (SU)s in the area of coverage. Moreover, pairing algorithms are used to choose a suitable PU to be coupled with a SU to obtain the optimum performance. Conclusions and future work suggestions are discussed in Chapter five.

CHAPTER TWO

BASICS OF THE NON-ORTHOGONAL MULTIPLE ACCESS AND SOME APPLICATIONS

2.1 Non Orthogonal Multiple Access Theory

The idea of NOMA depends on sharing more than one user in the same resource, the available NOMA techniques can broadly be divided into two major categories, i.e. power-domain NOMA and code-domain NOMA. In this thesis, the power domain part of NOMA with the assisted techniques is considered to enhance the performance for the next generation of wireless communications. Distribution of the energy between the users in different levels is the main idea of the NOMA system, where all users obtain their signals depending on the required power levels associated with their SNR. One of the vital mechanisms that are required for successful receiving via NOMA is the SIC. This mechanism is utilized for all NOMA users except the user that has a maximum level of allocated power, in which detection of this user's signal does not require SIC due to the assumption that all other users' signals are considered as additive noise. Figure 2.1 illustrates the basic idea of NOMA and its deference from the OFDMA, where NOMA permits numerous users to simultaneously use the same time-frequency resources with varying power levels, in contrast to OMA, which only permits each user to use the allotted time-frequency resources [1].

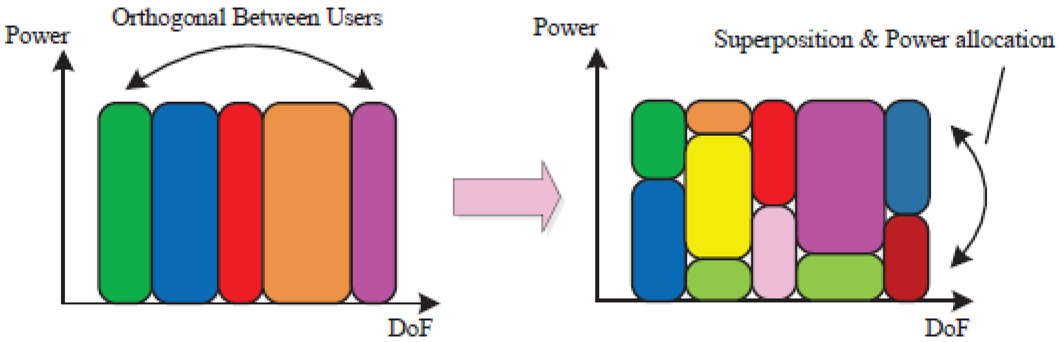

Fig. 2.1: Basic Idea of NOMA and OMA [2].

2.2 Successive Interference Cancellation

The SIC is an iterative algorithm, it is used in the case of multi-signals collected together, to separate the overlapping signals from each other which are considered interferences. One of the conditions for successful SIC is that the overlapped signals should have differences in their levels of power. Moreover, the SIC technique reconstructs the signal that has a higher level of power in the first step and subtracted it from the entire received signal to obtain the next-order signal that has a lower PAF and so on. By applying this approach, the SIC removes the effect of interferences caused by overlapping the signals in the power domain iteratively, by detecting and subtracting the signal of higher-order power till the signal of interest is detected.

2.3 Superposition Coding

Superposition coding is the main fundamental of NOMA theory. It is a model that produces one overlapped NOMA signal. It is a type of multiplexer in the power domain. The signals are combined after allocating the required portions of the available power via power allocation factor (PAF), in which the furthest user from the service provider, with low channel gain and higher attenuation, has obtained more portion of the power, while the near user has obtained less power due to having a high gain of channel.

2.4 Channel Capacity

The channel capacity also known as Shannon capacity has the maximum achievable data rate for reliable communication and it's measured by bit per second (bps) which can be expressed as:

$$C_{channel} = Blog_2(1 + SNR) \tag{2.1}$$

where $C_{channel}$ is the channel capacity, B is the passband system bandwidth in (Hz), and SNR is the signal-to-noise ratio, in this case, we apply SIC to remove interference from stronger users. It is noteworthy that the term SNR is replaced by the signal-to-interference-plus-noise ratio (SINR), to add the effect of interference on the capacity for interfered transmission environment like NOMA.

2.5 Spectral Efficiency (SE)

The spectral efficiency (SE) measures the system bandwidth (bit/s/Hz), bandwidth on the frequency spectrum is a limited and expensive resource; therefore, it must be used efficiently. SE is a measure of how efficiently a limited frequency spectrum (Hz) is used to transmit information data (bps). The equations below describe spectral efficiency.

$$\text{SE} = \frac{Data\ Rate(bps)}{System\ Bandwidth(Hz)} \quad \text{(bps/Hz)} \tag{2.2}$$

Spectral efficiency is a very important metric in wireless communication and expresses how efficient is the communication, and for reliable communication, the data rate must be less than the Shannon channel capacity.

2.6 System Throughput

The quantity of information units that a system can transmit within a specific period is known as throughput. It is widely used in systems ranging from organizations to different components of the computer and network systems. Theoretically, it is equal to Shannon's capacity represented in (2.1).

In this thesis, normalized throughput is used by considering a unity bandwidth as expression below:

$$\text{Throughput(R)} = Blog_2(1 + \ SINR) \quad \text{(bps/Hz)} \tag{2.3}$$

2.7 Outage probability

In cellular communications, outage probability is defined as the point at which the value of the received power goes below a threshold value, where at this value of power, it is referred to as the minimum SNR or SINR. The receiver is no longer within the range of BS, i.e. no services can be obtained below this value of power.

2.8 Downlink NOMA

The NOMA downlink scenario comes from the idea of collecting more than one user together by applying superposition coding. The important thing is how the power is allocated to several users in the same resource. This is because the NOMA system in this dissertation emphasizes power level as the coding of the users. The PAF for each user plays a vital role to satisfy user fairness. This can be implemented by evaluating the required portion of the power to be given to a particular user depending on its channel condition. In other words, edge users can obtain higher PAF than the users near the center of the service provider [3]. In traditional NOMA, all the users can share the available service depending on their circumstances theoretically [2]. However, pairing algorithms can be exploited to divide the users into groups of two, in which every two users can be paired to share the available power. Furthermore, PAF is allocated to each user in the created pair depending on the gain coefficient of the channel and the required data rate [26]. This can be explained by allocating a higher portion of the power to users that have low channel gain, while the users with strong channel gains are obtained a lower portion of the available power. The PAF, which is denoted in the thesis by (α), has a fraction value between zero and one, i.e. $(0 < \alpha < 1)$. Each user's signal from a base station (BS) to a particular user is scaled by a specific PAF before adding all the scaled signals together to create one NOMA signal. Any type of modulation scheme can be used with NOMA, i.e. Binary phase shift keying (BPSK), Quadrature phase shift keying (QPSK), M-ary Quadrature amplitude modulation (QAM), etc. For example, a modulation scheme that represents the binary bit (1) by (5v) and (0) by (-5v), and by assuming two NOMA users in the downlink mode, in which the far and near users are denoted as U_F and U_N, respectively. Depending on the NOMA theory, U_F needs more power than U_N due to their channel gain conditions. Therefore, U_F is given for example 70% of the available power, i.e. $\alpha_F = 0.7$, while the rest of the power is allocated to U_N by assuming $\alpha_F = 0.3$, this values is allocated to each user before superposition coding, then the superposition coding produce NOMA signal and then modulated over a carrier to sending to the receivers.

For a mathematical representation of this idea for those two users, the far-user signal S_F and near-user signal S_N can be created by choosing a specific PAF ratio of the available transmitted power (p_t). The equations below illustrate this operation by assuming that $p_t = 1$ watt.

$S_{Fs} = \sqrt{p_t \alpha_F} * s_F \Longrightarrow$ S_{Fs}==0.83*5=4.1volt

$S_{Ns} = \sqrt{p_t \alpha_N} * s_N \Longrightarrow$ S_{Ns} ==0.54*5=2.7volt

Where s_{Fs} and s_{Ns} are scaled the original signal of far and near users, respectively, which can be represented by any modulation scheme, in this example $s_{Fs} = s_{Ns} = 5$ volts, this values before multiplying by PAF.

After encoding the two signals by using the explained superposition coding, one coded NOMA signal is generated, S_{NOMA}, which means that by multiplexing several signals for multiple users, one signal is generated in the same frequency band, and is transmitted simultaneously to each user. The equation that describes the NOMA signal is expressed as

$$S_{NOMA} = \sqrt{P\alpha 1} * s1 + \sqrt{P\alpha 2} * s2 \tag{2.4}$$

Figure. 2.2 and 2.3 show the stages of NOMA encoding for two signals as explained above.

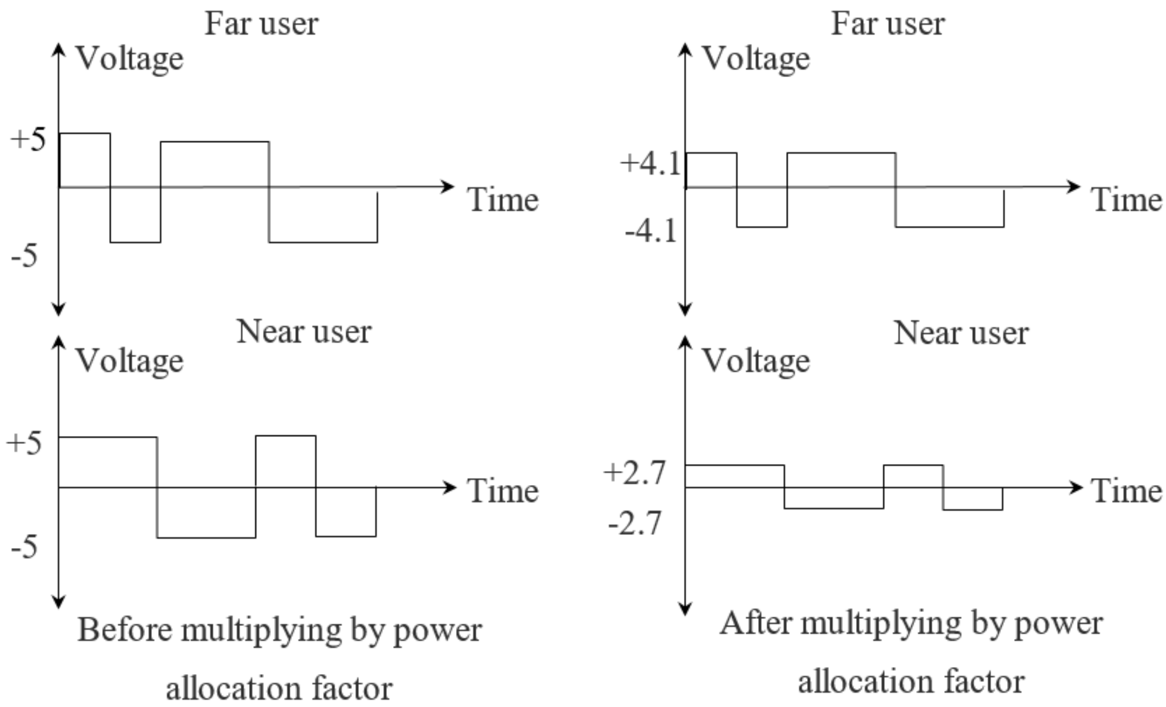

Fig. 2.2: Two-user signals before and after multiplying by PAF.

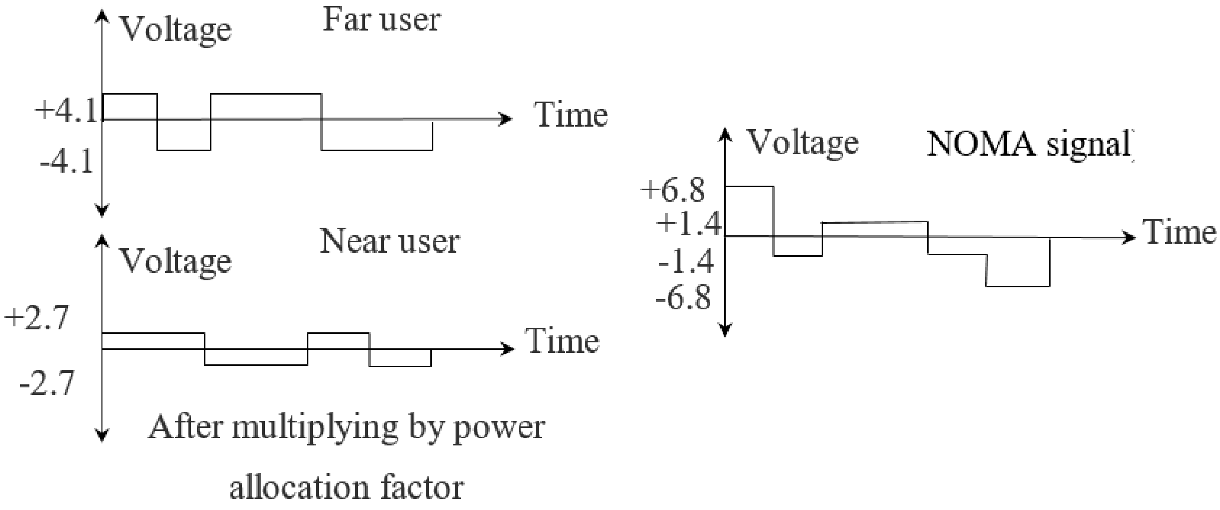

Fig. 2.3: The superposition coding to create one signal (NOMA signal).

When the NOMA signal is produced, it is sent to the two users over their channels, simultaneously. The transmitted signal is affected by the environment from the BS to each user's receiver, where the NOMA signal is suffered from many obstacles, reflection, attenuation, and abortions in some paths. This means that the signal can be reached its destination via a different path. Each path carries a copy of the signal with a different amplitude and phase. Sometimes the combination of the signals reached via multi-path can enhance the signal which is called constructive combination. If the signals reach out-of-phase versions, this causes a distinctive combination [51]. It is worth mentioning that if a line-of-sight (LOS) version of any signal arrives with the other path replicas, the channel of this transmission has Rician fading distribution. On the other hand, for the multi-path arrival of a signal without the LOS path, the distribution of the channel is called Rayleigh fading. Moreover, Additive white Gaussian noise (AWGN), with zero mean and variance σ^2, is added at each terminal.

Figure. 2.4 shows a traditional NOMA system for two users. The far user is denoted as user1 with a higher portion of the power and it communicates with the BS via a channel h_1, and near user which is denoted as user2 with the lower portion of the power and has a channel h_2. The power is allocated to each user depending on their channel circumstances.

The received NOMA signal at far user, y_F, and the near user, y_N, can be expressed as

$$y_F = h_1 S_{NOMA} + w_1 \tag{2.5}$$

$$y_N = h_2 S_{NOMA} + w_2 \tag{2.6}$$

where h_1 and h_2 represent frequency non-selective Rayleigh flat fading channels for the far and the near users, respectively, as illustrated in Figure. 2.4, in which $|h_1|^2 < |h_2|^2$. Moreover, w_1 and w_2 represent the AWGN added to the received signals at the far and near users' terminals as defined earlier.

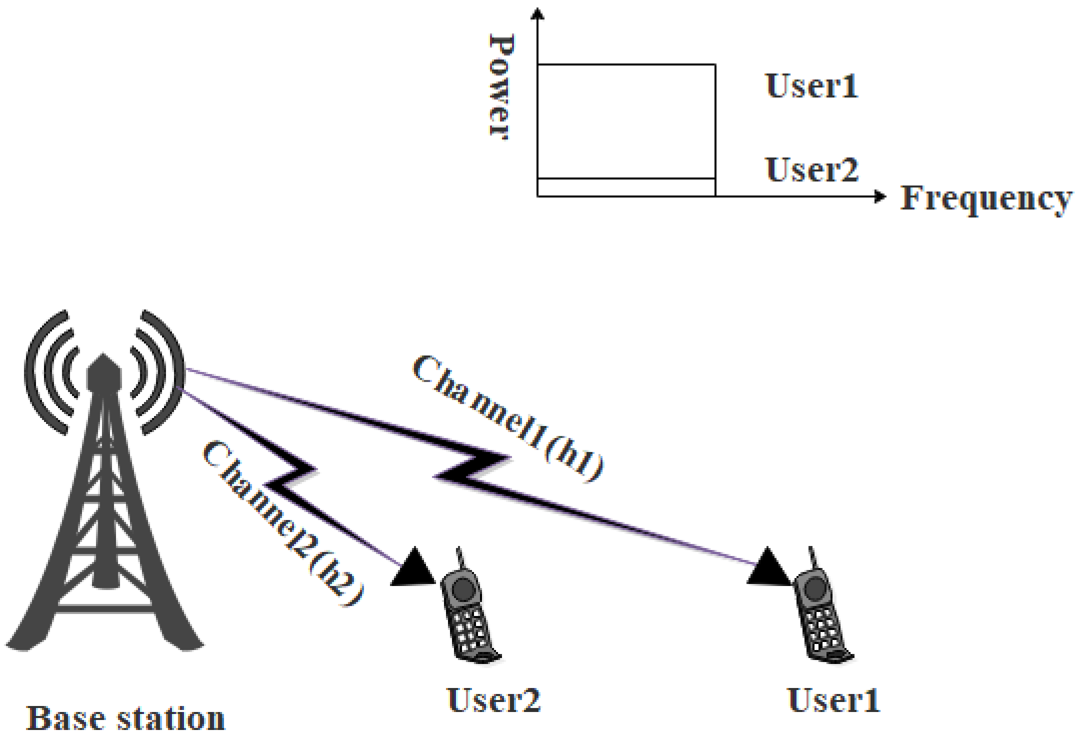

Fig. 2.4: Traditional NOMA system illustrating two user transmissions in the downlink mode.

After receiving the signal at the near user terminal, this user needs to apply SIC. The idea of SIC is summarized by reconstructing the strong signal, which is the signal of the furthest user. This user has the strongest signal that the NOMA signal is constructed from, as it has been given higher PAF for weak channel compensation. After detecting and reconstructing this strong signal, it is subtracted from the entire NOMA signal that leads to obtaining the next order user signal, which is the near user signal in case of assuming only two users.

The throughput in (bps/Hz) for the near user can be expressed as [17, 34]:

$$R_N = \log_2(1 + SNR) \tag{2.7}$$

in which SNR represents the signal-to-noise ratio after applying SIC, (2.7) can be written in more detail as:

$$R_N = \log_2\left(1 + \frac{\text{power signal}}{power\ noise}\right)$$

$$R_N = \log_2(1 + \frac{\mathrm{p_t}\ \alpha_2\ |h_2|^2}{\sigma_{w2}^2}) \tag{2.8}$$

It can be noticed that there is no effect of the far user's signal on the throughput of the near user due to applying the SIC, in which the strong signal of the far user is canceled if perfect SIC is assumed.

On the far user side, SIC is not employed, which means that the signal of the near user affects the far user signal. This is due to considering the small portion of the near user signal as an additive noise at this user terminal depending on NOMA theory. This means that the throughput of the far user, R_F, is affected by the interference of the near user, therefore, R_F can be expressed as [2,34]:

$$R_F = \log_2(1 + SINR) \tag{2.9}$$

Where the SINR can be written in detail as

$$R_F = \log_2\left(1 + \frac{\text{power signal}}{interference\ power + power\ noise}\right)$$

$$R_F = \log_2(1 + \frac{p_t\, \alpha_1\, |h_1|^2}{p_t\, \alpha_2\, |h_1|^2 + \sigma_{W1}^2}) \qquad (2.10)$$

To generalize the idea of NOMA for multi-user, (NOMA) communications can be illustrated in Figure. (2.5).

Figure 2.5 shows the mechanism of the SIC for MU-NOMA, in which k users are assumed, and the sequence is started from the far user to the near user, i.e. the strongest user to the weakest user. The farthest user is denoted as (s1) and the nearest user is represented as (sk). In this figure, decoding the kth user requires decoding all the users first and subtracting their detected signals from the whole received NOMA signal. Figure 2.6 shows the power distribution for those k users, and how the PAF is chosen to satisfy user fairness as discussed earlier in this chapter.

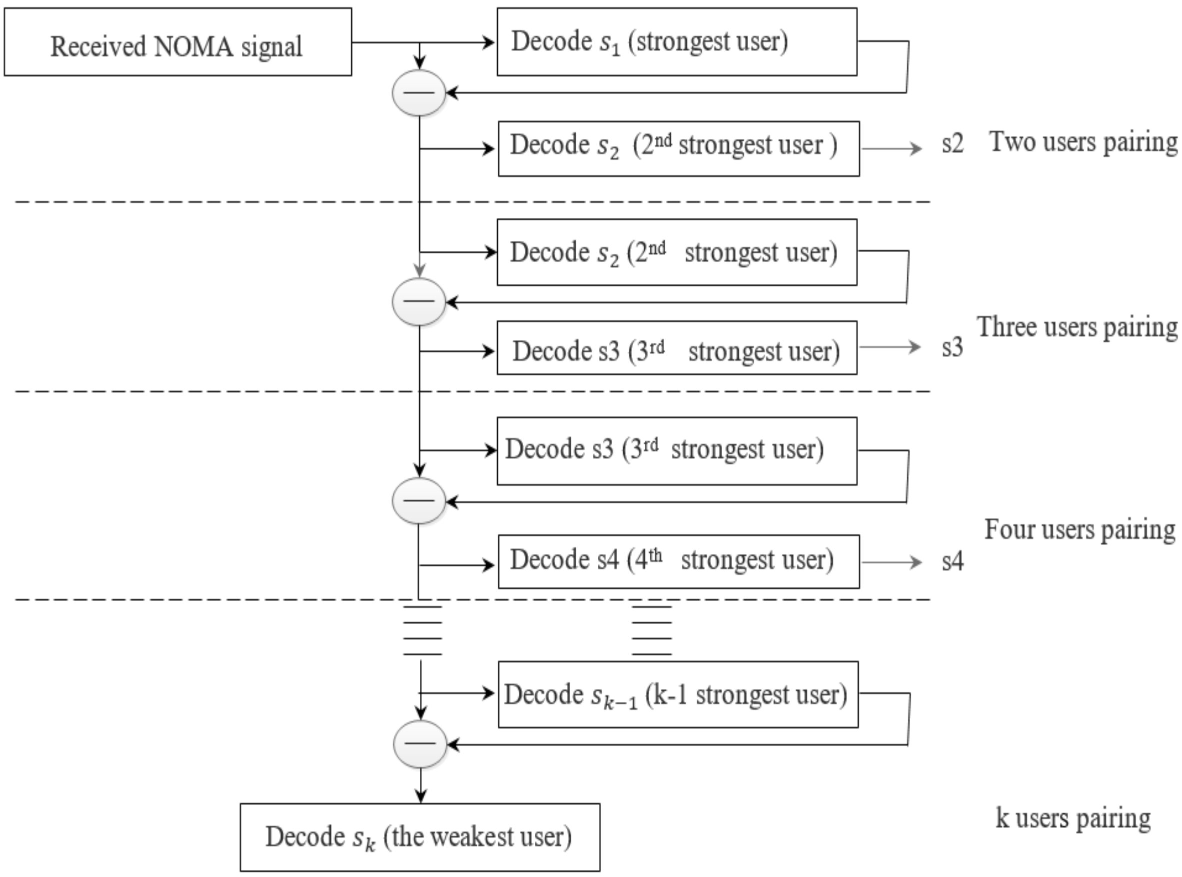

Fig. 2.5: the mechanism of SIC for MU-NOMA of k-users.

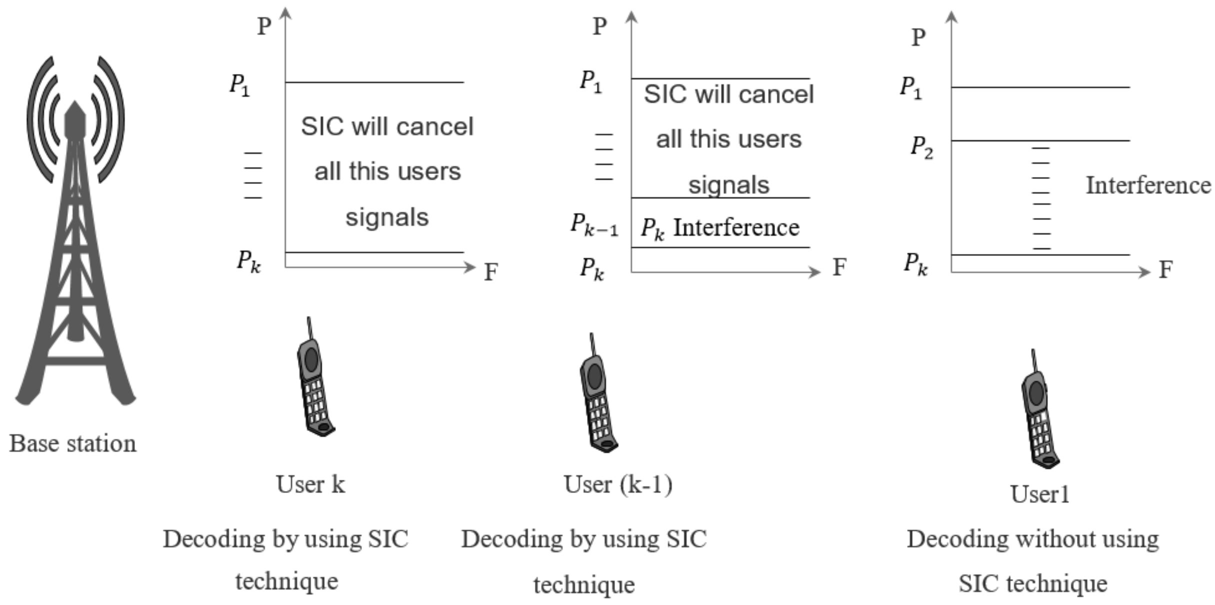

Fig. 2.6: Power distribution of k-users in the download phase of NOMA.

2.9 Uplink NOMA

As explained earlier in this chapter, NOMA depends on superposition coding in transmitting to collect multi-user in one signal and send it by one frequency at the same time. Moreover, in uplink NOMA there is no major difference in this theory, except that no need to apply PAF for the users depending on their locations and channel conditions. This is because the mechanism of PAF is already inherent in the channel gain/attenuation for each user. This means that each user sends its signal toward the BS by assuming the same level of power. The channels of the users in the uplink mode play a vital role to achieve differences in the received signals at the BS, in which all signals are combined as they are transmitted by exploiting the same frequency band. The SIC is required in this mode to detect the signal of the furthest user, which requires decoding the strongest signal, which is related to the near user in the uplink mode, and subtracting it from the combined NOMA signal, then the far user's signal can be detected with the interference-free condition. It is noteworthy that there is no need to use SIC for the nearest user, as it has the strongest signal, and other users' signals can be assumed as an additive noise only.

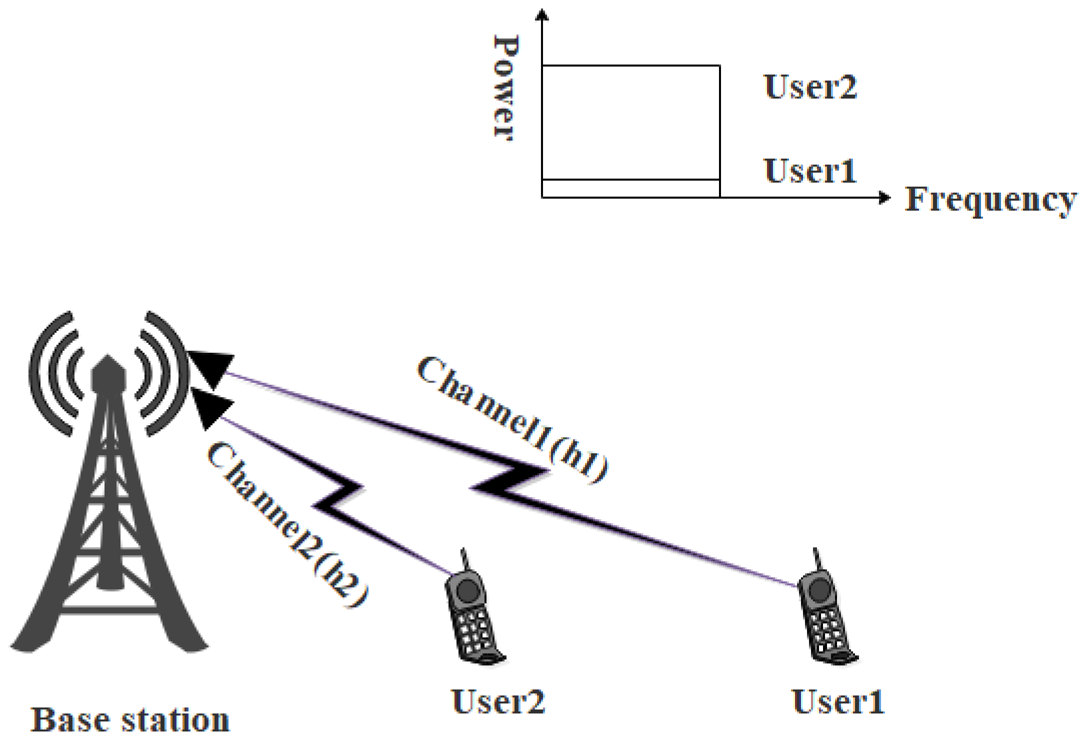

Fig. 2.7: The NOMA in the uplink mode where user2 with high power (high channel gain) (the near user), and user1 with low power (low channel gain) (the far user).

Figure 2.7 assumes the far user as (user1), and the near user as (user2), where channel coefficients for the far user and the near user are respectively denoted as h_1, and h_2, where $|h_2|^2 > |h_1|^2$. The received signal at the BS from those two users' is represented as

$$y_{UL} = h_1\sqrt{p_t}\, S_1 + h_2\sqrt{P}\, S_2 + w \tag{2.11}$$

Where the system always selects users for a pairing that has distinctive channel gain. In the uplink mode, the BS detects first the near signal, S_2, as it is the strongest signal in the superimposed signals of S_1 and S_2, followed by subtracting S_2 from the combined signals for the sake of decoding S_1 which is the weakest signal of the far user. This process of SIC in the uplink mode can be applied for more than two users in the same manner by detecting the user with the higher channel gain followed by applying subtraction to detect the next order user, which has a lower channel gain, and so on.

The throughput for the near user, R_{NU}, can be represented as [4]:

$$R_{NU} = \log_2(1 + SINR) \tag{2.12}$$

where the use of SINR is due to detecting the near-user signal without the need for the SIC. In more detail, (2.12) can be written as far user signal represent the interference.

$$R_{NU} = \log_2\left(1 + \frac{\text{power signal}}{the\ interferencepower + power\ noise}\right)$$

$$R_{NU} = \log_2\left(1 + \frac{\mathrm{p_t}\,|h_2|^2}{\mathrm{p_t}\,|h_1|^2 + \sigma_{BS}^2}\right) \tag{2.13}$$

where σ_{BS}^2 represents the AWGN added to the superimposed users' signals at the BS. Furthermore, The throughput for the far user, R_{FU}, can be written as (2.13), but with replacing R_{NU} with R_{FU} and SINR with SNR, in which the use of SNR is due to detecting the far user's signal after applying the SIC. In more detail, R_{FU} can be written as [2,4]:

$$R_{FU} = \log_2(1 + SNR) \tag{2.14}$$

$$R_{FU} = \log_2\left(1 + \frac{\text{power signal}}{power\ noise}\right)$$

$$R_{FU} = \log_2\left(1 + \frac{\mathrm{p_t}\,|h_1|^2}{\sigma_{BS}^2}\right) \tag{2.15}$$

It can be noticed that the far user throughput is not affected by the near user signal if perfect SIC is assumed to be applied at the BS, where total cancellation of the near user is achieved before decoding the far user signal.

On the other hand, the BS detects the near user's signal without using the SIC, therefore, the throughput of this user is affected by the interference caused by the far user. This point is very crucial, as choosing the pairs in the uplink mode requires coupling of two users with large differences in channel gain, i.e. distinguishing the energy gap between the paired users should be taken into account significantly. Fig. 2.8 shows the uplink mode of NOMA using k-users, the sequence of applying the SIC is considered in this figure. In this figure, the furthest user is the user1 in the uplink phase which is considered the weakest user in this group, while user k is the strongest user due to its higher channel gain. At the BS, detecting the user k's signal is applied first without using SIC, followed by the user k-1's signal by subtracting the user k's signal from the superimposed signals at the BS. This process is repeated by canceling the higher-order user's signal till reaches the furthest user, which is user 1 in this scenario. Therefore, all the users in the uplink NOMA mode can be considered interference-free users except the nearest user from the BS.

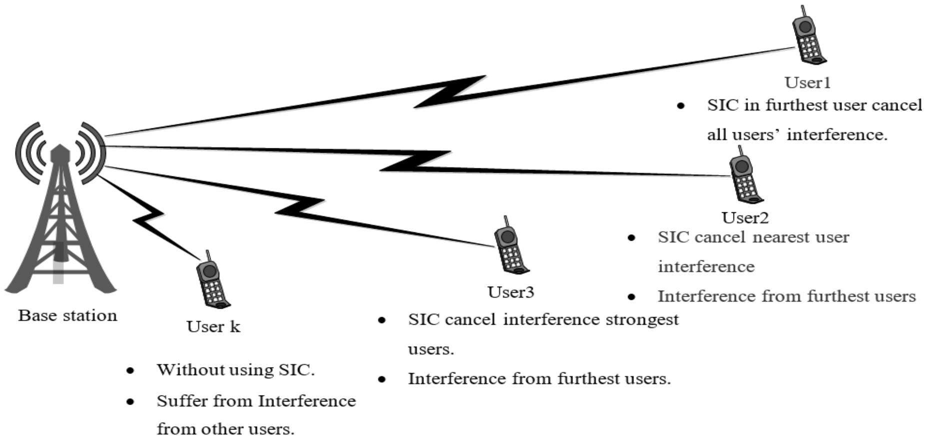

Fig. 2.8: NOMA uplink where the same resource is used to serve k number of users, where the user1 represents the furthest and the nearest user is denoted as user k.

2.10 Multiple Input Multiple Output (MIMO)

The increasing of using wireless communication due to the huge number of subscribers leads to finding ways to improve the higher demand for high data rates with acceptable outage probability and low bit error rate (BER). The multiple input multiple output (MIMO) technique, which uses multiple antennas at the transmitter and multiple antennas at the receiver, can meet these requirements. MIMO exploits spatial multiplexing, in which during this method the data send in parallel, where the data launches from all antennas of the transmitter via uncorrelated channels to reach the receiver antennas with different paths, i.e. multi-path transmission, which caused significant gain diversity. Multiple copies of the signal arriving at the receiver ensure a constructive combination of the transmitted signal, which consequently, improves the data rate and reduces the BER significantly. Figure. 2.9, shows communication between a BS with a user by using the MIMO technique, each of the BS and the user are equipped with two antennas. This means that the transmission occurs via four channels, which are $\boldsymbol{H} = [h_{11}\ , h_{12};\ h_{21}, h_{22}]$

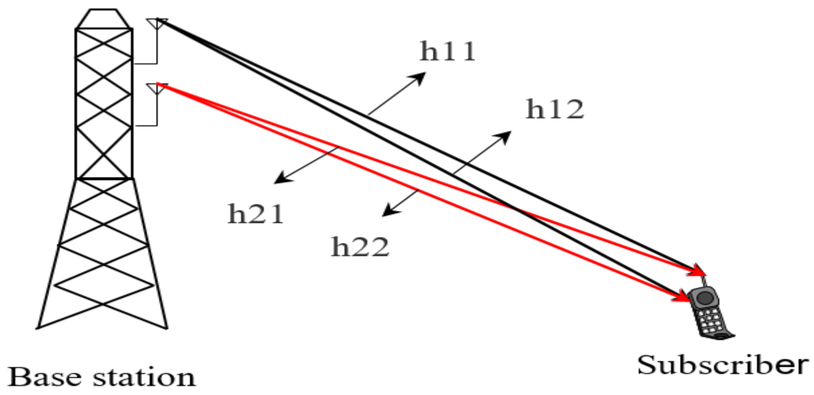

Fig. 2.9: MIMO system with two antennas at the transmitter and two antennas at the receiver.

Suppose that the received signal at the user terminal, $\boldsymbol{y},$ in which the MIMO system in the downlink mode is assumed, i.e. from the BS to the user. The vector $\boldsymbol{y}$ contains two elements at each time instance for each antenna, i.e. $\boldsymbol{y} = [y_1 , y_2]$.

$$y_1 = h_{11}x_1 + h_{12}x_1 + w_1$$

$$y_2 = h_{21}x_2 + h_{22}x_2 + w_2 \tag{2.16}$$

where x_1 and x_2 are the transmitted signal for a vector $\boldsymbol{x} = [x_1 , x_2]$ from the first and second antennas at the BS, respectively,w1 and w2 are AWGN. The two above equations can be rewritten in a form of a matrix:

$$\boldsymbol{y} = \boldsymbol{Hx} + \boldsymbol{w} = \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} w_1 \\ w_2 \end{bmatrix} \tag{2.17}$$

Therefore, if the NOMA system discussed earlier is changed from a single antenna to MIMO, (2.7) can be rewritten as

$$R_N = \log_2\left(1 + \frac{\mathrm{p_t}\alpha_2 \ |\mathrm{h11+h12 + h21+h22}\,|^2}{\sigma^2}\right) \tag{2.18}$$

According to (2.17), the effect of MIMO can be shown clearly on the overall system performance is enhanced significantly by increasing the channel gain, which means that the SNR is increased.

2.11 Cognitive Radio technique

Cognitive radio (CR) techniques are used to solve spectral scarcity. This solution is achieved by exploiting the resources that are allocated for a user that has the right to use a specific frequency. This user in CR networks is called a PU, by other users that do not have these rights are called the SU, where this idea is achieved by employing spectrum sensing by the transmitter continuously to track the existence of the PU, in which the PU absence allows the transmitter to serve the SU. During that, the SU continues monitoring the PU return to the network, where the latter has the priority to use the service in the coverage area. At the instant of returning the PU to the network, the SU has to leave this spectrum resource and look for another one. Figure. 2.10 demonstrates the essential principle of the CR network, in which the spectrum is shown for the PU in the upper part, while the SU exploits this spectrum temporarily in the absence of the PU.

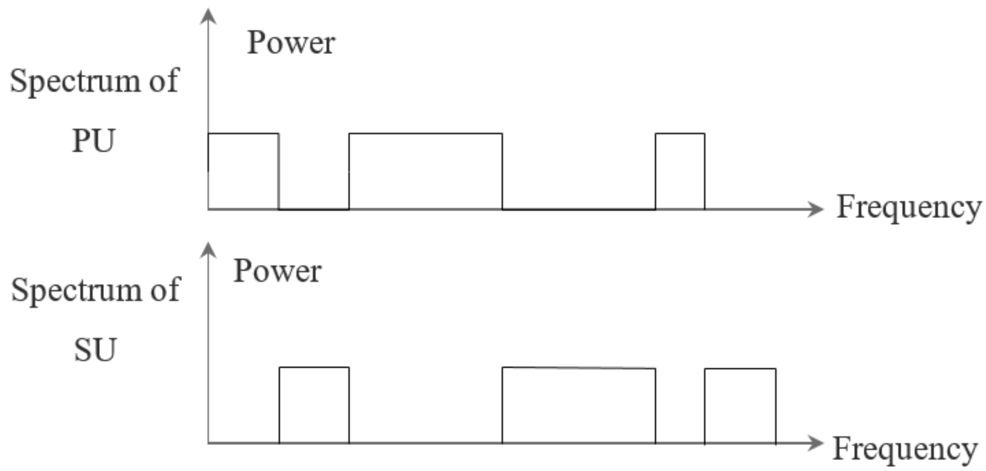

Fig. 2.10: The principle of the CR network, where the spectrum of PU and the spectrum of the SU are at the top and the bottom, respectively.

The techniques that are used in spectrum access are Interweave technique, Underlay overlay, and hybrid methods. In interweave spectrum access, as mentioned earlier in this section, the SU has shared the spectrum with the PU in case of the PU's absence. Under certain interference strength constraints, the PU and SU of the underlay spectrum accessing method can both use the spectrum at the same time, at the same frequency, and in the same place. But due to the restricted power allocation, underlay spectrum accessing is constrained by the low data speeds, this limitation is to avoid interference on the PU. As for the overlay technique, it works to avoid interference, and the hybrid combines Interweave, underlay, or overlay methods in the absence of the PU, where the SU full freely exploits the PU's resource, and when the PU presents, the SU is forced to leave and look for another resource [35]. Figure 2.11 demonstrates concepts of overlay and underlay CR techniques, where PSD in the figure means power spectral Density and P mean primary.

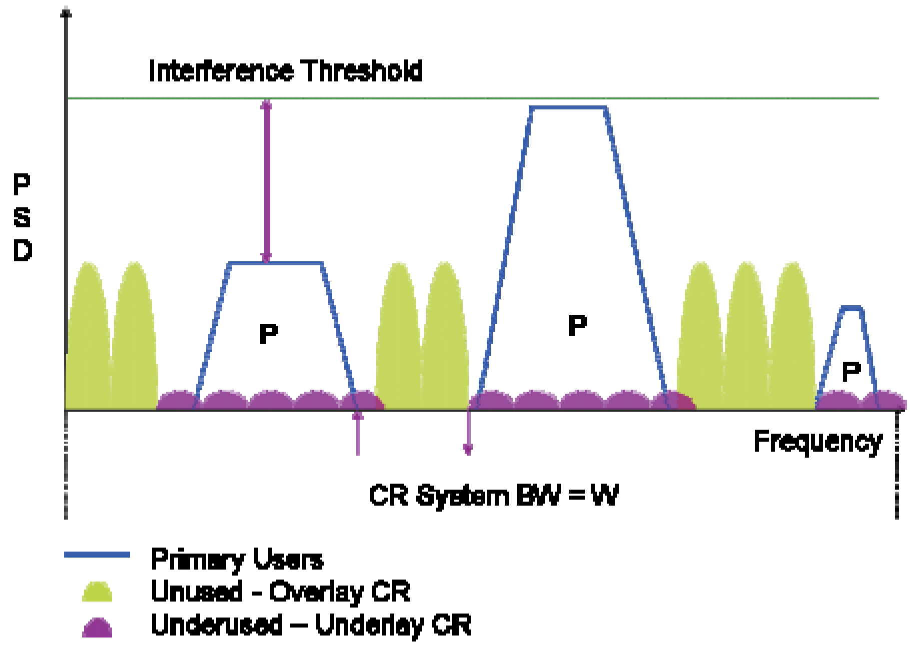

Fig. 2.11: Cognitive radio techniques(underlay and overlay CR)[52].

In the NOMA system, the complexity of the CR system is significantly reduced compared to the traditional CR system, in which spectral sensing is not required, but an adequate separation between the PU and the SU is required, to ensure employing PAF to distribute the available power between the two users. In brief, the same NOMA theory is used for CR-NOMA by ensuring the PU can communicate with its required rate to obtain its required QoS, i.e. the required rate and the acceptable outage probability, and the rest of the power is allocated to the SUs in the area of coverage. Different scenarios are investigated and analyzed later in this thesis in Chapter 4.

CHAPTER THREE

Cognitive Radio-Based NOMA for the Next Generation of Wireless Communications

3.1 Introduction

The CR technique is used to improve spectrum utilization, the traditional CR technique needs spectrum sensing to enable the SU users to utilize the resources of the PU users. The NOMA is another face-to-CR technique where the CR did not need spectrum sensing, where SU users directly utilize the PU user's resources in condition this utilization does not affect the PU user's QoS, i.e. the efficiency can be achieved by enabling a secondary user to use the available spectrum resources at any time, with its required minimum rate, without any effects on the target rate of a primary user. Moreover, the PAF and the pairing algorithm in the downlink and uplink modes will play an important role to implement the scenario idea of the proposed system as will be seen later. Two performance metrics have been used to examine the proposed CR-NOMA system which are the outage probability and the achievable rate. Furthermore, the effect of changing the distance of the secondary user on these two performance metrics is considered accompanied by modifying the PAF to control the target rates of all users without any system degrading. To the best of the researcher’s knowledge, these contribution points have not yet been taken into account in the literature.

3.2 System Modeling and Implementation

In this system model, it has been considered that all users in the coverage region of a BS are divided into groups of two users by utilizing a pairing algorithm. The latter examines the channel gains of these users with the BS, for the sake of creating M groups for $2M$ users. The examined channel gains are then sorted in descending order, i.e. $h_1 \geq h_2 \geq \ldots \geq h_{2M}$. The BS pairs the nearest user, i.e. the user of the channel gain h_1, with the furthest one, i.e. the user of the channel gain h_{2M} to create the first group, and the process is repeated for the rest of the users in the same manner. It is noteworthy that this type of pairing technique is called near-far pairing (N-F). Another type of pairing is called near-near far-far (N-N, F-F), which considers the pairing of successive users depending on their distances from the BS, i.e. pairing the users of channel gains h_1 and h_2 together and so on.

Table 3.1: The parameters of the proposed Algorithm 1 (effects of transmitted power on PU and SU in uplink and downlink phases).

Parameter	Value	Name
B	1MHz	System Bandwidth
N	10^5bit	Number of bits per symbol
d_p	300m	Primary distance from BS
d_s	1000m	Secondary distance from BS
β	4	Path loss exponent
$\propto_p$	0.2	PAF for PU in the Downlink phase, in the uplink phase the users send their message by the same power
$\propto_s$	0,8	PAF for SU in the Downlink phase, in the uplink phase the users send their message by the same power
r_p	2bps/Hz	Primary user target rate
r_s	1bps/Hz	Secondary user target rate
P	0dBm to 40dBm	Transmitted power in Downlink
P	-20dBm to 40dBm	Transmitted power in Uplink
The simulation was done by Matlab code. Frequency non-selective Rayleigh fading channel is assumed in all transmission between the users and the BS, and the noise effect is taken into account by AWGN with zero mean and variance σ^2		

Algorithm 1: N-F Paring For NOMA Users
1: Input← channel gains of all users, $\boldsymbol{H} = [h_1 , h_2 , \ldots , h_{2M}]$, number of groups, M, number of users, 2M.
2:Sort the channel gain of all users in descending order: $h_1 \geq h_2 \geq \ldots \geq h_{2M}$
3: Define the set of channel gains U = $\{h_1 , h_2 , ..., h_{2M}\}$
4: For k = 1 : M
5: H_j = {}
6: H_{max} = max {U} , H_{min} = min {U}
7: $H_j = H_{max} \cup H_{min}$
8: U = U=U(k+1:end-1)
9: end for
10: Output: Set of pairs.

By using this algorithm, the rest of this chapter will emphasize the performance of two users only, without the loss of generality.

3.3 Modeling of NOMA signal in the uplink mode

In this section, NOMA for two users communicating with a base station (BS) is considered for the uplink and downlink phases as shown in Figure.3. 1. The near user is denoted as U_n that have a distance of d_n away from the BS, while the furthest user is denoted as U_f with a d_f distance away from the BS. It has been considered that all users and the BS are equipped with a single antenna. All channels in this communication system are assumed as flat Rayleigh fading channels and modeled as $h_i \sim CN(0, \sigma_{h_i}^2)$ for $i \in \{n, f\}$ for the near and far users, respectively, and $h_n > h_f$.

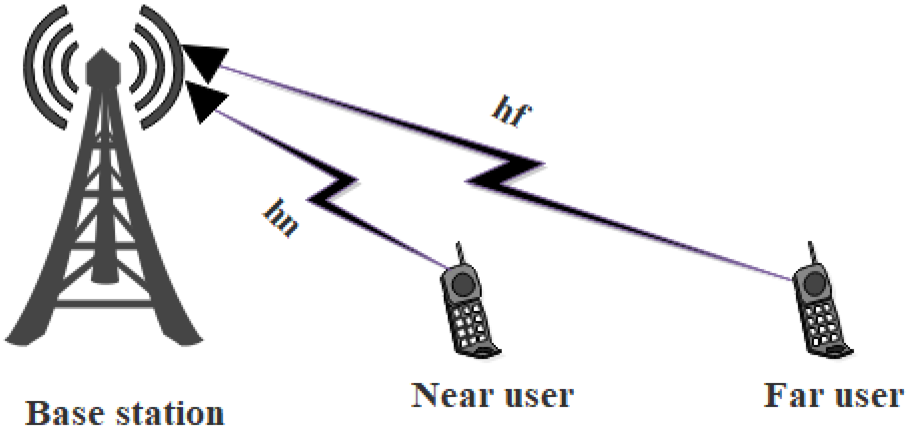

Fig. 3.1: NOMA in the uplink mode for the two users with different channels conditions $h_n > h_f$.

It is noteworthy that all channels are defined as a function of path loss exponent in which the obstruction in the building and the environment are taken into account.

The two users transmit their signals to the base station with a constant power with different channel gain depending on their location from the base station which can be expressed as:

$$h_i = \frac{1}{\sqrt{2}} \sqrt{d_i^{\beta}} \tag{3.1}$$

where β is the path-loss exponent, and $i \in \{n, f\}$ for the near and far users, respectively. Moreover, the received signal at the BS can be expressed as

$$S_{NOMA}^{UL} = \sum_{i \in \{n,f\}} \sqrt{p}\, h_i \; x_i + w \tag{3.2}$$

where p is a constant to represent available power at each user's terminal that is used to transmit its signal towards the BS, $x_i \in \{x_n, x_f\}$ to represent the transmitted signal of each user that a modulation scheme of binary phase-shift keying (BPSK) is considered in this chapter. Furthermore, $w \sim CN(0, \sigma_w^2)$ represents the additive white Gaussian noise.

In this case, after receiving the NOMA signal by the BS, a near user's signal can be extracted directly from the entire NOMA signal as it has higher power than the far user's signal due to the differences in the channel attenuations that each user passes through. A mechanism of successive interference cancellation (SIC) should be applied to detect the far user's signal, which is received with low power since it passes through a high attenuation channel. This mechanism can be achieved by utilizing the detected near user's signal by reconstructing it and then applying subtraction from the NOMA signal to obtain the Far user's signal. It is noteworthy that the direct detection of the near user's signal in the BS, without taking into account the combined far user signal, causes an amount of interference that can be ignored or considered as an added noise. Therefore, the throughput of the near user[3] can be expressed as in equation (2.12).

On other hand, SIC, which is used to detect the far user's signal, would cancel the interference of the near user's signal, therefore, it can be considered theoretically that the detected far signal is interference-free, and its throughput is expressed in equation (2.14).

3.4 Modeling of NOMA signal in the downlink mode

In this mode, the BS communicates with two users as shown in Figure 3.2, in which the two users exploit the same frequency resources simultaneously, but by employing power domain multiplexing. This technique of superposition coding is achieved by allocating power for each user depending on its distance from the source. By using the power allocation factor (PAF), a higher portion of the available power is given to the far user, while lower power is given to the near one, where the summation of this factor for all users must be a unity, i.e. $\sum_{m=1}^{M} \alpha_m = 1$, where M represents the total number of users in the coverage area that uses NOMA techniques to apply communication services. Without loss of generality, two users are considered in this chapter by exploiting the pairing algorithm [20][26], in which the PAF is defined as: $\alpha_{f+}\alpha_n = 1, \alpha_f > \alpha_n$, and in the BS the superposed generated NOMA signal for those two users can be expressed as

$$S_{NOMA} = \sqrt{p\alpha_f}\, x_f + \sqrt{p\alpha_n}\, x_n \tag{3.3}$$

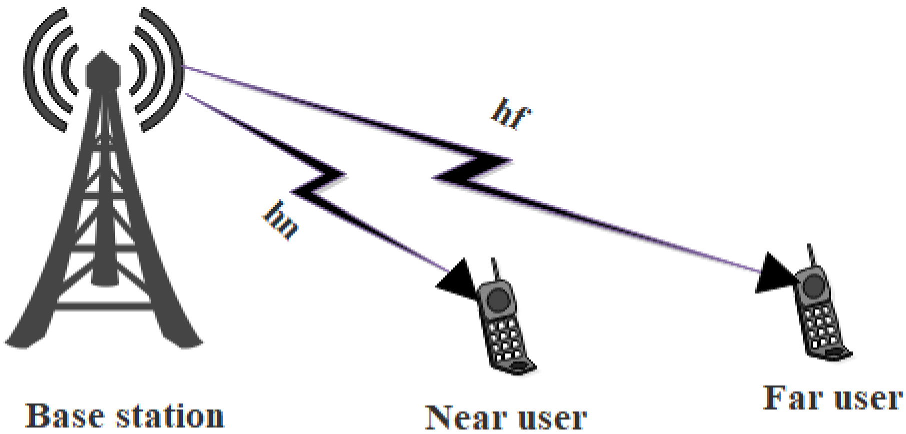

Fig. 3.2 Downlink NOMA from a base station for two users.

The received signal at the i^{th} user, i.e. $i \in \{n, f\}$

$$s_i = S_{NOMA}\, h_i + w_i \tag{3.4}$$

At the far terminal, direct detection is applied without the need for applying SIC, since higher power is allocated to this user, and by assuming the near user is an added noise. Therefore, the throughput of this user is obtained similarly to the method used in [2,34], as in equation (2.10).

On the other hand, SIC is required to detect the near user's signal at its terminal by detecting first the far user's signal, followed by subtracting it from the received NOMA signal to obtain the near user's signal. This process is illustrated in Figure 3.3. Therefore, it has been expressed that the throughput of the near user, is derived by following the same way used in [17, 34] as in equation (2.8).

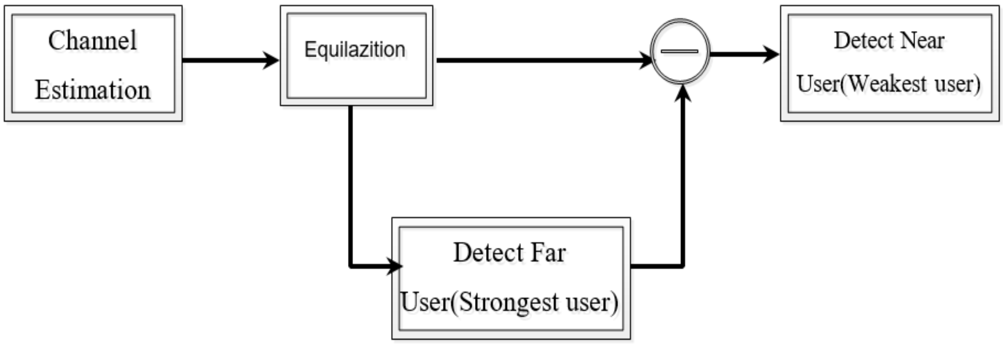

Fig. 3.3: SIC mechanism for two users

3.5 NOMA-based CR modeling

For the next generations of wireless communications, CR based on the NOMA technique can enhance spectral utilization and efficiency significantly. This can be achieved by sharing the available system spectrum among the users under the coverage of network service. As mentioned earlier and by using the paring algorithm, two users can share the spectrum resources by assuming one of the users is a PU, while the other is the SU. As defined in the theory of CR [5-8], the SU can make a transmission in a particular network using the same spectrum resources without affecting the target rate of the PU. This can be implemented in different scenarios [12-17]. NOMA can be exploited with CR to allow SU to access the network at any time, i.e. without using spectrum sensing, by changing its rate so PU can keep its required rate without any degradation in its performance.

Different scenarios for CR-based-NOMA are considered, in which the PU and SU can be at a different distance from the BS and in the uplink and downlink transmission modes. Algorithm 2 shows the stages of processing followed by pairing two users in the coverage area of the BS. It can be noticed that PAF plays a significant role to keep the performance of each user at its acceptable target. The proposed algorithm treats any degradation in the performance of the two users by changing the PAFs and repeating the examination of the CR-NOMA. Otherwise, the BS can use Algorithm 1 to select another PU with a different rate and/or channel condition to pair it with a particular SU.

Table 3.2: The parameters of the proposed Algorithm 2 (Effects of PAF and pairing algorithm).

Parameter	Value	Name
B	1MHz	System Bandwidth
N	10^5bit	Number of bits per symbol
d_p	300m Downlink,200m Uplink	Primary distance from BS
d_s	From 300m to 1000m by step 100m	Secondary distance from BS
β	4	Path loss exponent
$\propto_p$	$\propto_p$=1-$\propto_s$	PAF for PU in the Downlink phase, in the uplink phase the users send their message by the same power
$\propto_s$	{0.55:0.05:0.9)	PAF for SU in the Downlink phase, in the uplink phase the users send their message by the same power
r_p	2bps/Hz	Primary user target rate
r_s	1bps/Hz	Secondary user target rate
P	20dBm Downlink, 10 dBm in Uplink	Transmitted power
The simulation by Matlab code. Frequency non-selective Rayleigh fading channel is assumed in all transmission between the users and the BS, and the noise effect is taken into account by AWGN with zero mean and variance σ^2		

Algorithm 2: Examine CR-NOMA performance
1: Input←The paired PU with SU via Algorithm 1. 2: Input← PU & SU distances, d_p and d_s, to measure the channel gains. **2:** Measure the channel gains of PU and SU, h_p and h_s. **3:** Set $\alpha_p \in \{0,1\}$, and $\alpha_s = 1 - \alpha_p$. 4: Input← The target rate of PU, r_p, and the acceptance rate of SU, r_s. **5:** Calculate R_p and R_s using Equations (2.8), (2.9), (2.12), and (2.14) depending on the situation of the users. **6:** Initialize counters, pi, $\boldsymbol{i} \in \{\boldsymbol{p}, \boldsymbol{s}\}$. **7:** For $i = 1$: N ←Start Iteration to evaluate the outage probability, P_{out}. **8:** if $R_i < r_i$ **9:** $p_i = p_i$+1 **10:** end of the iteration **11:**$P_{out}^i = \frac{p_i}{N}$ **12:** if P_{out}^i< $\overline{P_{out}^i}$ ←$\overline{P_{out}^i}$=Acceptable outage probability. **13:** Alter α_p and α_s then Go to 4. **14: Output:** Optimized CR-NOMA

3.6 Simulation Results and Discussions

In this chapter, the CR-based NOMA system is considered for two users by applying the paring algorithm. Different scenarios have been taken into account to investigate this system by obtaining the error probability, the outage probability, and the system throughput. A frequency non-selective Rayleigh fading channel is assumed in all transmission between the users and the BS.

In the first case, the CR's PU is considered located near the BS, with a distance of $d_p = 300m$, PAF of $\alpha_p = 0.2$, while the secondary user of CR is away, i.e. far with a distance of $d_s = 1000m$, PAF of $\alpha_s = 0.8$. Figure 3.4 and Figure.3.5 show the outage probability and the achievable capacity, respectively, of this scenario over different transmitted powers in (dBm). It can be seen that the near primary user with lower PAF has a better outage probability than the far secondary user when the target rates for the primary and the secondary users are assumed as $r_p = 2$ bits/sec/Hz (bps/Hz) and $r_s = 1$ bps/Hz, respectively. Moreover, the throughput of the far secondary user reaches saturated achievable capacity after approximately $25\ dBm$, around 2.3 bps/Hz, without any effect on the throughput of the primary user, which the latter keeps increased achievable capacity with increasing the transmitted power as shown in Figure 3.5.

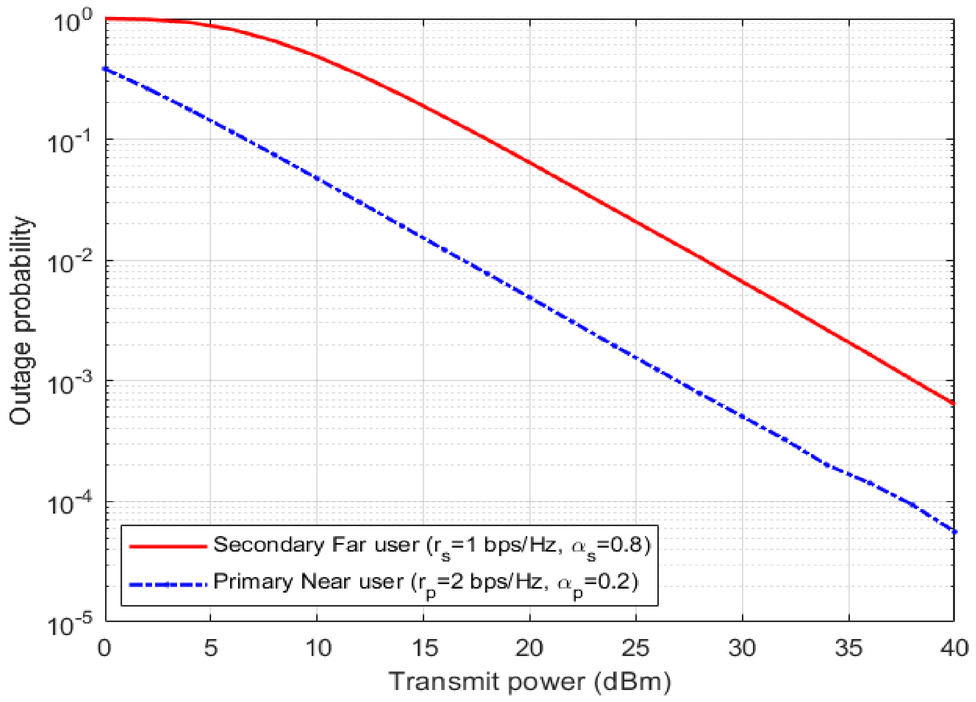

Fig.3.4: The outage probability of two users CR based-NOMA in the downlink mode with $d_p = 300m$ and $d_s = 1000m$.

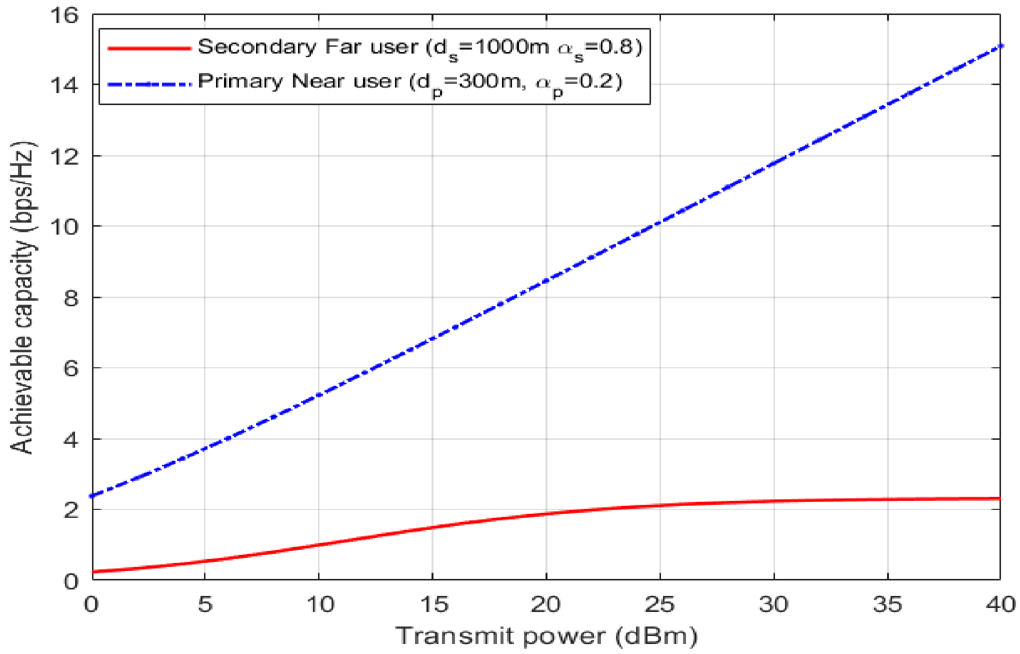

Fig.3.5: The achievable capacity of two users CR based-NOMA in the downlink mode with $d_p = 300m$ and $d_s = 1000m$.

Figure 3.6 shows the outage probability of the two users in the uplink mode, it can be noticed that the outage probability of the primary user has better performance at low transmitted power, i.e. below 22 dBm, and its outage probability becomes without changes after that due to interference of the far user and the nearest user (strongest user) of NOMA system in uplink phase don't apply SIC the latter used for weakest users, while the secondary far user outperforms the primary near user after this transmitted power because of applying SIC to remove the interfered primary user's signal.

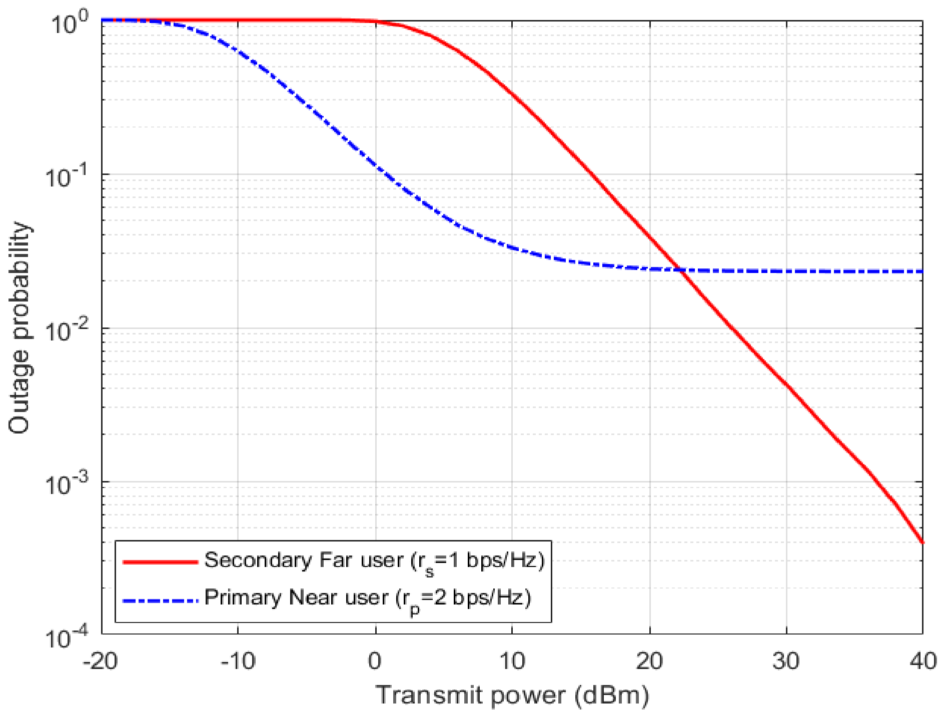

Fig. 3.6: The outage probability of CR based-NOMA for the two users in the uplink mode with $d_p = 300m$, and $d_s = 1000m$.

In Figure 3.7, the achievable rates are shown for the two selected users under the same specifications. It can be noticed that under these distances away from the BS, the primary user has better capacity at a transmitted power below 30 dBm, this user reaches a saturated rate after this value with 7 bps/Hz, because of a significant interference caused by the secondary user, since the near user is detected directly without applying SIC in this mode as explained earlier in section (3.3). Additionally, the secondary far user has a better rate after 30 dBm, as this user is considered interference-free after SIC.

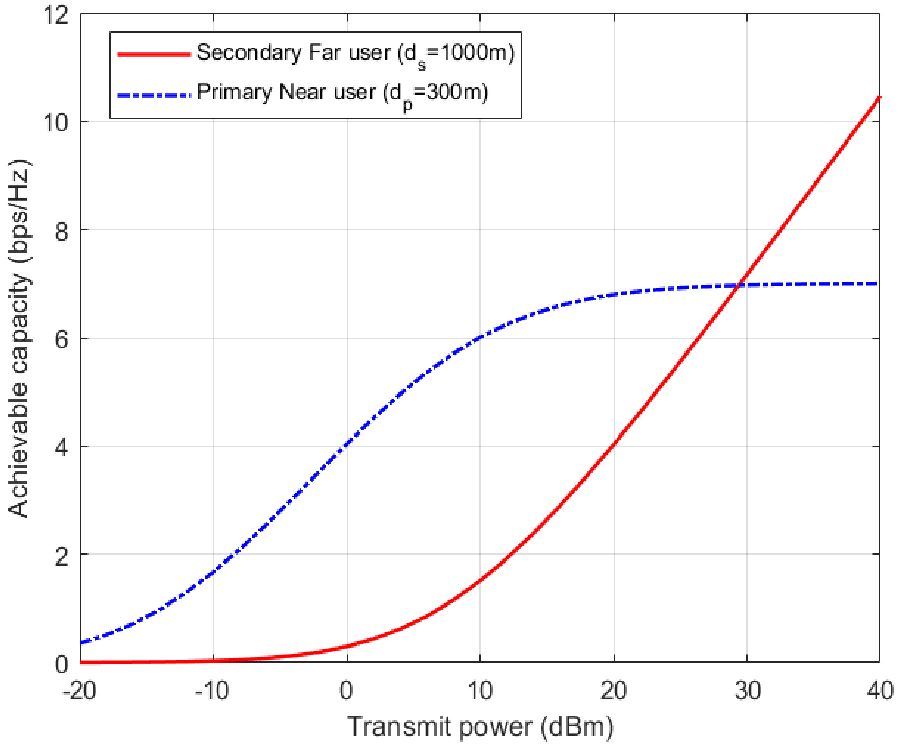

Fig. 3.7: The achievable capacity of two users CR based-NOMA in the uplink mode with $d_p = 300m$ and $d_s = 1000m$.

In Figure 3.8, the outage probability of CR-based-NOMA is obtained by assuming different locations of the secondary user away from the BS, i.e. from $300m$ to $1000m$, while the primary user keeps its position at $200m$ from the BS. The target rate of the primary user is assumed 2 bps/Hz, while the minimum required rate of the secondary user is equal to 1 bps/Hz. As the distances are changed for the secondary user, the PAF is changed to tackle the increasing attenuation caused by the channel due to the added distances. It has been assumed that $\alpha_s = \{0.55: 0.05: 0.9\}$, and $\alpha_p = 1 - \alpha_s$ as mentioned earlier in section (3.4) regarding NOMA theory. It can be seen that the primary user has a better outage probability, but its performance degraded when its PAF is reduced to compensate for the secondary far user which has additional attenuation caused by the added distances.

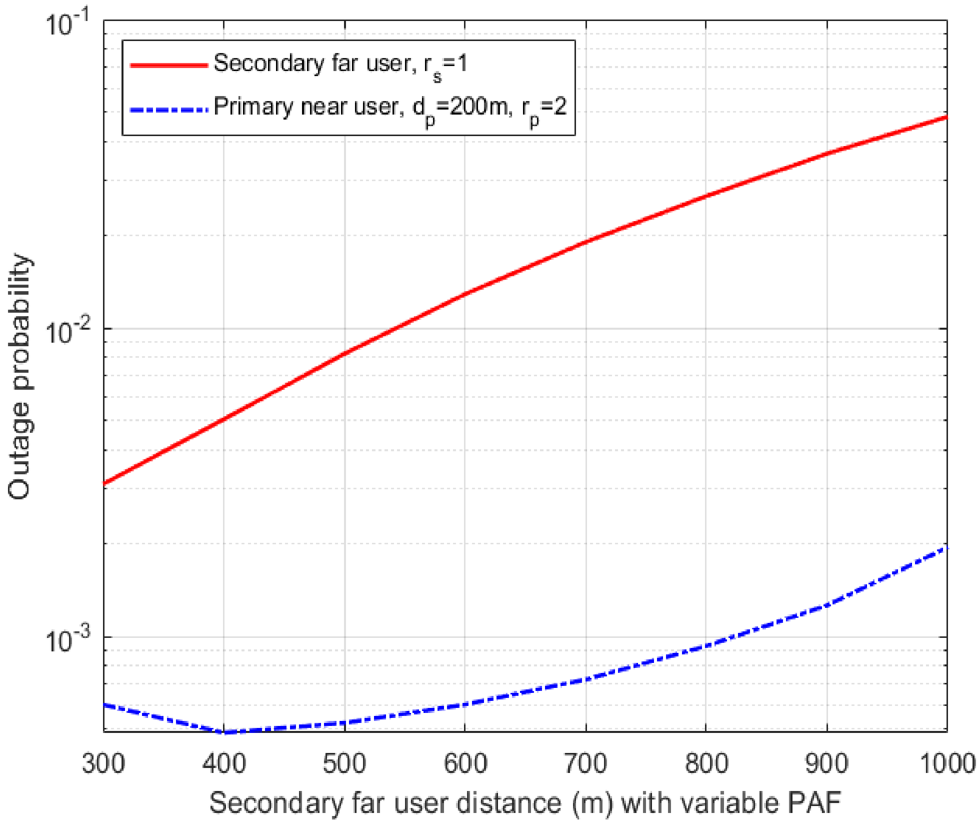

Fig. 3.8: CR-based-NOMA outage probability of two users in the downlink mode for $d_p = 200m$ with variable d_s and with different PAF.

The same scenario is considered in Figure 3.9 to evaluate the achievable rate of those two CR-NOMA users. It can be noticed that the primary user outperforms the secondary one significantly. However, it has about 2 bps/Hz degradation in its capacity, i.e. from 12 bps/Hz to about 10 bps/Hz, when the distance of the secondary user increased from $300m$ to $1000m$, respectively, due to the same reason mentioned above regarding reducing the PAF of the primary user.

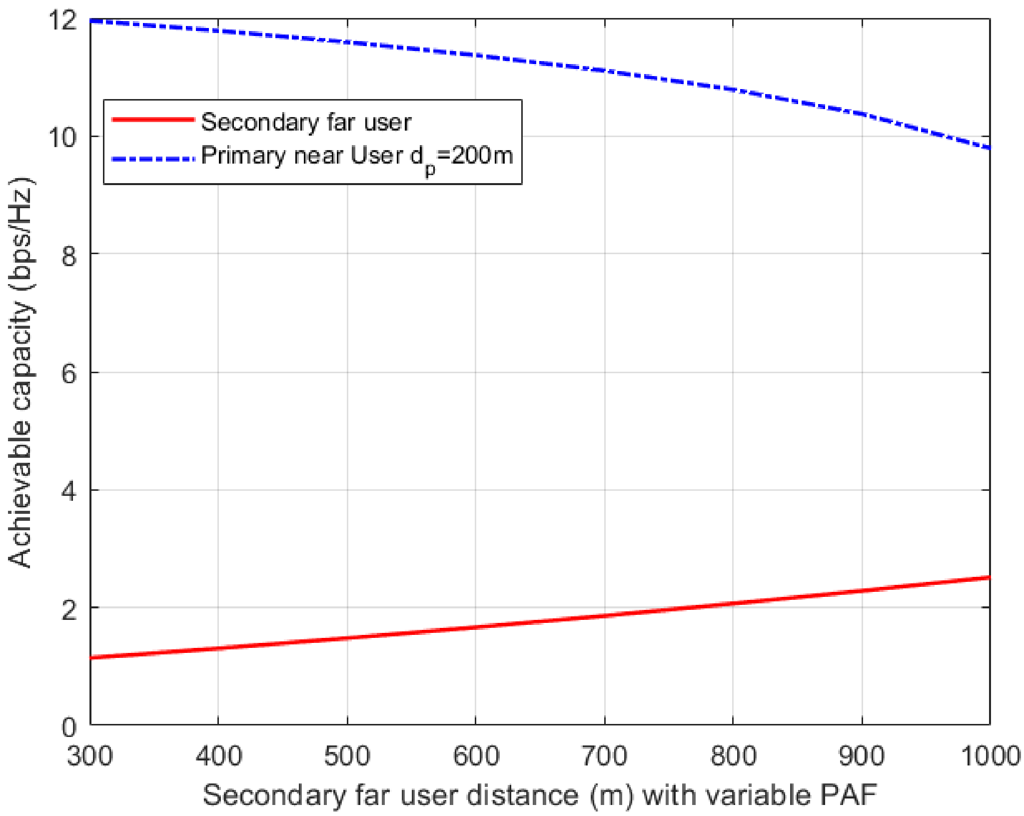

Fig. 3.9: CR-based-NOMA achievable capacity of two users in the downlink mode for $d_p = 200m$ *with variable* d_s *and with different PAF.*

In the uplink mode, and for the same specification considered for the last two figures in the downlink mode, Figure 3.10 and Figure 3.11 show the outage probability and the achievable rate for the two users, respectively. It is noteworthy that in this mode the PAF does not apply to the users, since the distances from the BS are in charge to add different attenuation to the transmitted signals.

In Figure 3.10, the primary user shows better performance when the secondary user becomes much furthest since the interference of the latter is reduced, while the outage probability of the secondary user is degraded significantly due to the higher attenuation caused by the added distances. This figure illustrates that when a secondary user has a distance about $570m$ away from the BS, i.e. $370m$ away from the primary user, the latter outperforms the former significantly. This result can be added to the pairing algorithm to choose the suitable secondary user that utilizes the spectrum without any effects on the primary user.

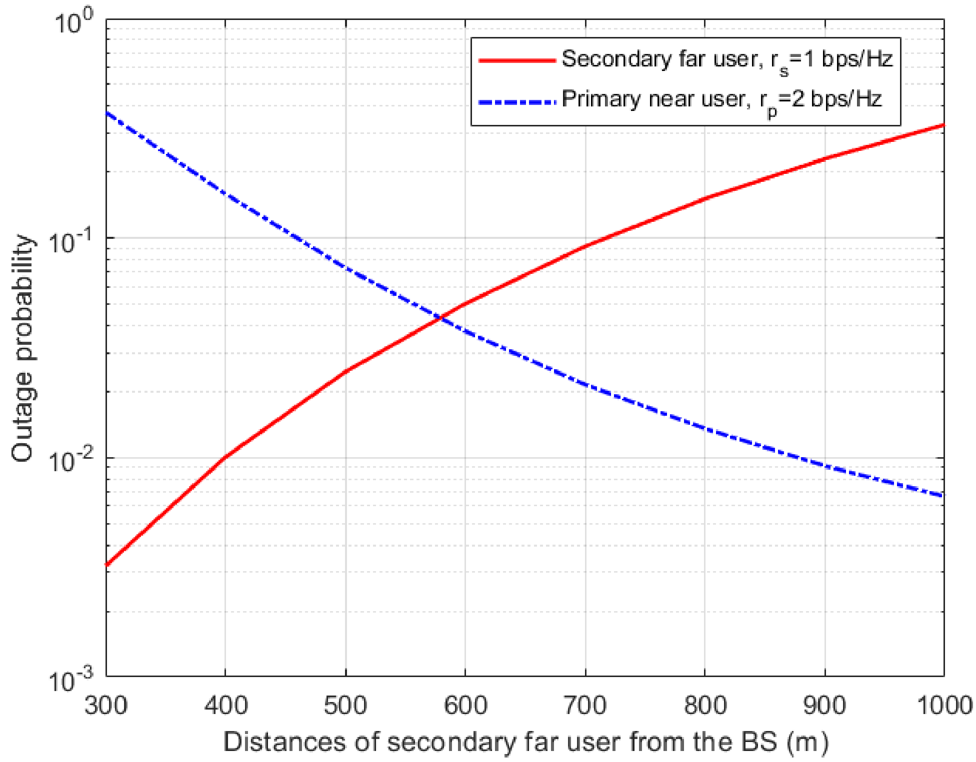

Fig. 3.10: CR-based-NOMA outage probability for two users in the uplink mode for $d_p = 200m$ with variable d_s.

The achievable throughput in the uplink mode with increasing the distance of the secondary user away from the BS is illustrated in Figure 3.11. It is noticeable that the primary user can achieve a rate of 3 bps/Hz when the secondary user at $300m$ away from the BS, i.e. when the two users are near each other. On other hand, the rate of the primary user reaches more than 8 bps/Hz when the secondary user becomes $1000m$ away from the BS. This is because the interference is reduced significantly.

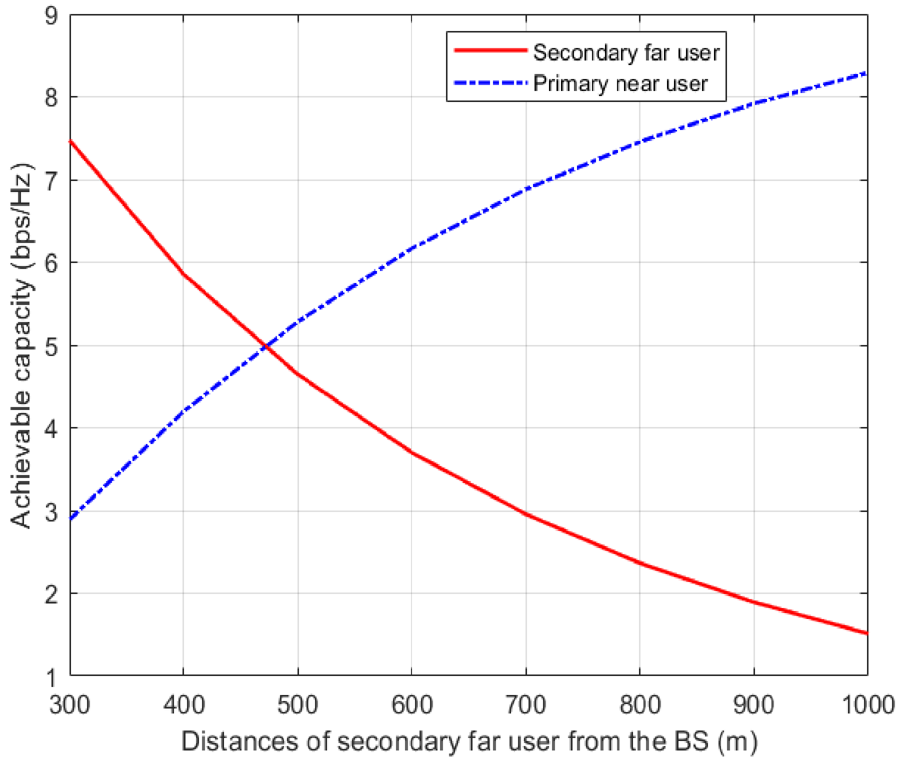

Fig. 3.11: CR-based-NOMA achievable capacity for two users in the uplink mode for $d_p = 200m$ with variable d_s.

CHAPTER FOUR

Algorithms and Throughput Analysis of Cognitive Radio-based MIMO-NOMA

4.1 Introduction

Based on CR- MIMO-NOMA, algorithms for various scenarios have been proposed in which secondary users (SU)s can access service networks in the presence of primary users (PU)s without the need for spectral sensing. The cases which are taken into consideration assume different locations of PUs and SUs near and far from the service provider. Moreover, all scenarios give the PUs the priority to access the wireless network with their target rate, without any degradation in their achievable throughputs and outage probabilities. Furthermore, mathematical analysis and expressions have been derived for the required power allocation factor (PAF), and the capacity of each user in the different scenarios, in addition, to evaluating the outage probabilities for the SUs after allocating the available power depending on their channel circumstances.

4.2 SYSTEM MODELING

In this section, three scenarios are considered for MIMO-NOMA-CR. The investigated cases in this section are intended to study and analyze different scenarios for serving numerous SUs as a CR based on the NOMA technique, without the need for spectral sensing, and in this context, pairing algorithms are proposed for coupling a PU with an SU, in a group of PUs and SUs with different locations, for the sake of optimum performance for both users in the created pair, giving the priority to the PU to reach its target rate. This can be achieved by applying the suitable PAF that satisfies user-fairness for the SUs, after supplying the PUs with their required power to achieve their target throughput. Moreover, mathematical expressions for the achievable rates are obtained for each user depending on deriving the signal-to-interference plus noise ratio (SINR) for each case. Additionally, the outage probability, which is defined as the probability when the received throughput for a user falls below a minimum acceptable rate for that user, is simulated for each SUs depending on the required rate of that user.

4.3 The First Scenario

In the first scenario, MU transmission is considered by employing NOMA-MIMO-based CR. All the users and the BS are equipped with N_{tx} and N_{rx} antennas for transmitting and receiving purposes, respectively. The pairing model is utilized in the Base station for coupling the number of users we refer to this number as NU in this scenario in the coverage area together. Rayleigh fading channels are considered to model all the transmission media between the BS and users. Moreover, the path-loss exponent of β is assumed to represent the effect of the environment, i.e. shadowed urban cellular radio.

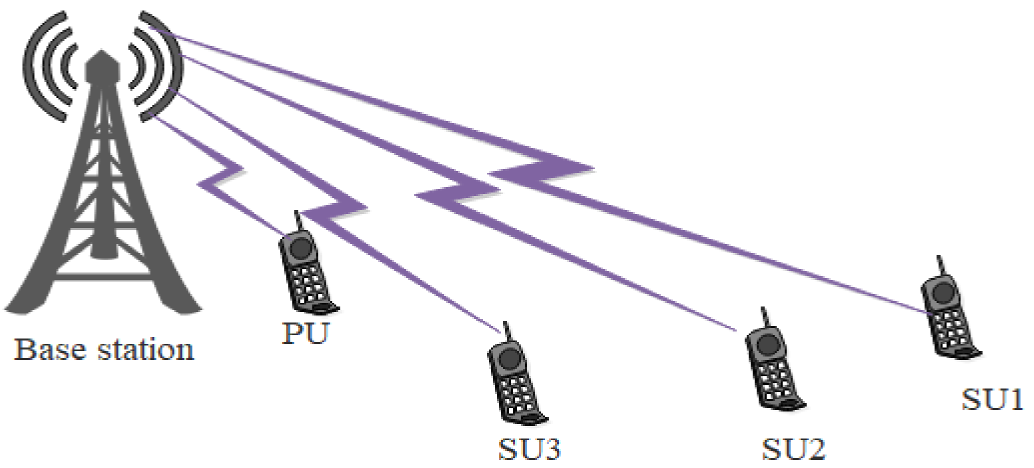

Fig. 4.1: The system model of user pairing among a primary user and three secondary users in CR-NOMA networks.

In this scenario, MIMO-NOMA-CR is applied for pairing between users (N user), in which the nearest user is assumed to be a PU, while the rest of the users, i.e. $NU-1$, is considered as SUs, which are the furthest from the BS than the PU. The users from the furthest to the nearest location from the BS are denoted as U_i for $i = 1, 2, 3, \dots, NU$, and U_{NU} is to represent the near PU. The channel coefficients for all these users are expressed as $\boldsymbol{h_i} \sim CN\left(0, d_i^{\beta}\right)$ where d_i is the distance of the i^{th} user from the BS, and β represents the path loss exponent as defined earlier, also $|\boldsymbol{h_1}| < |\boldsymbol{h_2}| < |\boldsymbol{h_3}| < \cdots < |\boldsymbol{h_{NU}}|$, and $|\boldsymbol{h_{NU}}| = |\boldsymbol{h_P}|$. The main idea of this scenario is how to share the resources of the near PU with the far SUs by allocating the required portion of the available power to the PU to ensure that its target rate is reached, and the acceptable outage probability is satisfied.

The rest of the available power is then given to the SUs depending on their locations, according to equations (4.6) to (4.8) This process can be achieved via applying a power allocation factor (PAF) for each user, which is the value of a fraction between zero and one, i.e. $PAF \in \{0,1\}$.and the summation of PAF for all including the primary user must be equal to (1).

In this thesis, the symbol α is denoted for this factor, in which α_p belongs to the PAF of the primary user, while α_{s1}, α_{s2}, and α_{s3} are the PAFs of the secondary users from the furthest to the nearest user from the primary user, respectively. In this scenario, the system performance is investigated using two important metrics, which are the throughput and the outage probability, over a range of values of the signal-to-noise ratio (SNR), which can be defined in general as $\Omega = \frac{p_t}{\sigma^2}$, where p_t and σ^2 represent the transmitted power and the variance of the additive white Gaussian noise (AWGN), respectively. In the theory of NOMA, successive-interference cancelation (SIC) should be applied to users which are near the Base station, since these users have been given a lower portion of the power due to their higher SNR, i.e. lower channel attenuations. This operation is achieved by detecting the next furthest user and subtracting the reconstructed signal from the entire received NOMA signal. Moreover, SIC is applied to all users except the furthest SU user from the BS, which has a higher portion of p_t. In this chapter, this idea of NOMA is utilized and employed, but firstly the required power is allocated to the PU to maintain its target rate, then the rest of the power is distributed among the SUs depending on their locations.

As we apply SIC to the PU, since it is the nearest user from the BS as it has been assumed in this chapter, the PU is considered an interference-free user. This assumption is valid if perfect interference cancellation is applied, i.e. residual interference is equal to zero. Therefore, the capacity of the PU (R_p) can be expressed by using the Shannon capacity theorem, which is defined as $R = B\log_2(1+\Omega)$ [14],where Ω SNR. Therefore, for normalized bandwidth (B), i.e. B=1Hz, the capacity of the PU can be expressed as:

$$R_p = \log_2\left(1 + \frac{p_t\,\alpha_p|\boldsymbol{h_p}|^2}{\sigma^2}\right) = \log_2\left(1 + \Omega\,\alpha_p|\boldsymbol{h_p}|^2\right) \tag{4.1}$$

For other users, the SIC will be applied to remove the signals for users with higher orders, i.e. the users which have higher PAF. This means that the third user in our case will apply SIC to remove the signals of the second and the first users, successively, while considering the signal of the fourth user, which is the PU user here, as just an additive noise. This leads to evaluate the capacity using the formula $R = B\log_2(1+\gamma)$, where γ represents the SINR. Therefore, the rate of the third SU can be expressed as:

$$R_{s3} = \log_2\left(1 + \frac{\Omega\,\alpha_{s3}\,|\boldsymbol{h_{s3}}|^2}{\alpha_p\,\Omega\,|\boldsymbol{h_{s3}}|^2+1}\right) \tag{4.2}$$

Similarly, for the second SU, SIC is achieved to remove the signal of its higher order user, which is the first SU only, while the third SU and PU signals are considered additive noise. The throughput of this SU can be written as:

$$R_{s2} = \log_2\left(1 + \frac{\Omega\, \alpha_{s2}\, |\boldsymbol{h_{s2}}|^2}{(\alpha_{s3}+\alpha_P)\, \Omega\, |\boldsymbol{h_{s2}}|^2+1}\right) \tag{4.3}$$

Finally, the first SU, with the higher PAF as it is the furthest user from the BS, can detect its signal without the need to apply SIC by considering all other users' signals as just noise. The capacity of this user is expressed as:

$$R_{s1} = \log_2\left(1 + \frac{\Omega\, \alpha_{s1}\, |\boldsymbol{h_{s1}}|^2}{(\alpha_{s2}+\alpha_{s3}+\alpha_P)\Omega\, |\boldsymbol{h_{s1}}|^2+1}\right) \tag{4.4}$$

Moreover, to evaluate the PAF for each user in the proposed CR-NOMA, it is required first to evaluate α_p that ensures the target rate of the PU. This step can be calculated by taking the logarithmic power of (1) as:

$$\alpha_P = \frac{2^{R_P-1}}{\Omega\, |\boldsymbol{h_p}|^2} \tag{4.5}$$

In this section, it has been assumed that the furthest SU from the BS will be allocated a portion of K_1 of the residual power after allocating α_P to the PU. This means that the PAF of the furthest user is expressed as:

$$\alpha_{s1} = K_1(1 - \alpha_P) \tag{4.6}$$

Additionally, the SU user that followed the furthest user is given a portion K_2 of the remained power after supplying the PU and the furthest users with their required power. This can be expressed as:

$$\alpha_{s2} = K_2\, [1 - (\alpha_P + \alpha_{s1})] \tag{4.7}$$

Finally, the last SU which is the nearest SU to the PU can be given the rest of the power as:

$$\alpha_{s3} = [1 - (\alpha_P + \alpha_{s1} + \alpha_{s2})] \tag{4.8}$$

It is noteworthy that equations (4.1) to (4.8) evaluate the throughput and the PAF for each user in a system that employs MIMO-NOMA-based CR. For comparison purposes, the throughput and the PAF for each user in a system using a traditional MIMO-NOMA, i.e. without CR, can be evaluated as:

First, it has been allocating for example K_1 of the available power to the furthest user, therefore, $\alpha_{s_1} = K_1$. Then, it has been considered that the second user has been allocated $\alpha_{s_2} = K_2$ portion form the remained power, which can be expressed as $\alpha_{s2} = K_2(1 - \alpha_{s1})$. The third user can be given K_3 form the rest of the power, which can be expressed as $\alpha_{s3} = K_3[1 - (\alpha_{s1} + \alpha_{s2})]$. Finally, the fourth user in the traditional MIMO-NOMA, which represents the PU in the MIMO-NOMA-CR and it has the nearest position from the BS, is given the remained portion of the transmitted power due to its higher channel gain. Therefore, the PAF of the nearest user, which is denoted as α_4, can be expressed as $\alpha_{s4} = [1 - (\alpha_{s1} + \alpha_{s2} + \alpha_{s3})]$. Furthermore, equations (1) to (4) are valid to evaluate the throughput of the users for a traditional MIMO-NOMA by just replacing the term R_P by R_4 and α_P by α_4. Furthermore, the factors K_i for $i \in \{1,2,3\}$, are arbitrary factors that can be chosen to satisfy the user-fairness of all users that uses traditional NOMA, and the SUs that use NOMA-based CR. Moreover, these factors can be evaluated using optimization methods by taking the logarithmic power from equations (4.1) to (4.4), successively.

Table 4.1: The parameters of the proposed Algorithm 1 (pairing algorithm contains 1 PU and 3 SU).

Parameter	value	Name
B	1MHz	System Bandwidth
N	10^5bit	Number of bits per symbol
$d_p(d_4)$	300m	Primary distance from BS
d_{s3} d_{s2} d_{s1}	400m,700m,800m,	(SU)s distance from BS respectively
B	4	Path loss exponent
r_p	2.5bps/Hz	Primary user target rate
r_{s3} , r_{s2} , r_{s1}	(2,1.5,1)bps/Hz	(SU)s target rate respectively
p	0dBm to 30dBm	Transmitted power
N_{tx}	2	Number of antennas of MIMO at the BS
N_{rx}	2	Number of antennas of MIMO at the receiver
The simulation is done by Matlab code. Frequency non-selective Rayleigh fading channel is assumed in all transmission between the users and the BS, and the noise effect is taken into account by AWGN with zero mean and variance σ^2.		

Algorithm 1: MIMO-NOMA-CR the 1st Scenario
1: Input← channel gains of all users [$\boldsymbol{h_1}$, $\boldsymbol{h_2}$, $\mathbf{h3}, \mathbf{hp}$],   2: Input← selecting arrange of SNR to represent the available power at the BS.   3: Evaluate the target throughput of the PU, R_P, via eq.(1).   4: Evaluate the required PAF of the PU, α_P, via eq. (5).   5: Allocate the remained available power for the SUs' depending on their locations from the BS via eq. (6)-(8).   6: Evaluate the capacity of each of the SUs via eq. (2)-(4).   7: Examine the outage probability of each user of this network.

4.4 The Second Scenario

In this scenario, as shown in Figure.4.2, MIMO-NOMA-CR is proposed for eight users, without the loss of generality. In this network, four PUs, with different target rates, are located near a BS. Moreover, another four SUs are located far from the BS with different locations, i.e. the nearest SU is located beyond the furthest PU. In this case, a pairing algorithm is employed for the sake of coupling each SU with a suitable PU to produce four pairs. The pairing can be achieved by coupling a PU with a minimum target rate with an SU that needs a maximum throughput and vice versa. This approach plays a vital role with NOMA-CR systems, in general, to obtain the optimum achievable rate with acceptable outage probability.

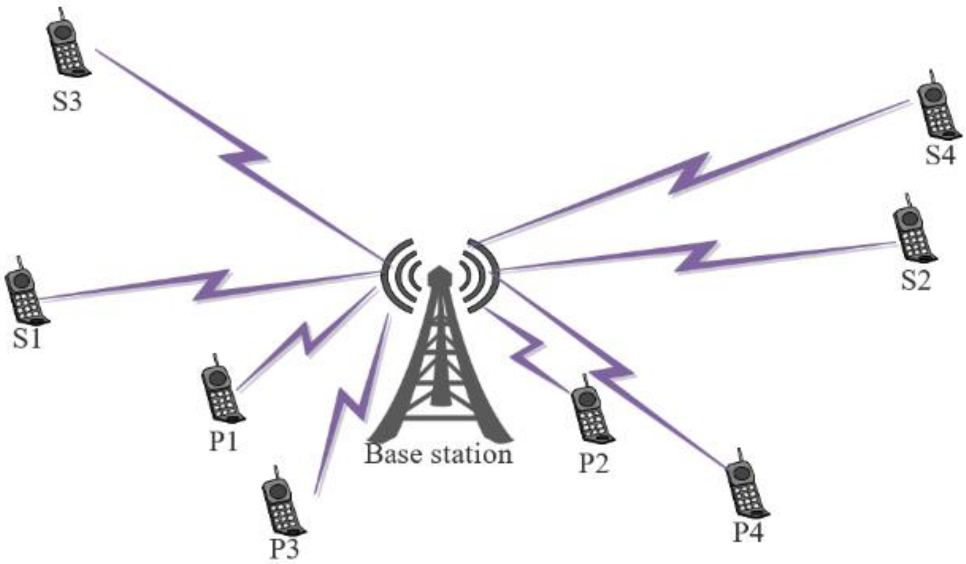

Fig. 4.2: Service provider to serve 4-PUs and 4-SUs for the 2nd scenario.

As has been mentioned earlier, the PAFs for the paired users are allocated to participate in the available power depending on the required target rates. In other words, distinguishing the power gaps between each PU with an SU that satisfies the required rate for each user is the key to choosing which SU is paired with a PU, and this relies on the distance of each user with its channel gain with the BS. Again, SIC will be used at the nearest user to remove the interference of the far user's signal, while it is not required for the farthest user as the interference of the other user's signal can be neglected by assuming it as additive noise.

For modeling, this scenario, each of the four primary users, which are distributed in positions near the BS, experiences a frequency non-selective Rayleigh fading channel which can be defined as $\boldsymbol{h_{Pi}} \sim CN(0, \sigma^2_{h_{pi}})$, with $i \in \{1,2,3,4\}$, and $|\boldsymbol{h_{P_1}}|^2 > |\boldsymbol{h_{P_2}}|^2 > |\boldsymbol{h_{P_3}}|^2 > |\boldsymbol{h_{P_4}}|^2$. Moreover, the required rates for these four PUs are denoted as $R_{P_1}, R_{P_2}, R_{P_3,}$ and R_{P_4}. Regarding the SUs, the four SUs are assumed with the same channel distribution defined above for the PUs, i.e.

$\boldsymbol{h}_{S_i} \sim CN\left(0, \sigma^2_{h_{S_i}}\right)$, and $\left|\boldsymbol{h}_{S_1}\right|^2 > \left|\boldsymbol{h}_{S_2}\right|^2 > \left|\boldsymbol{h}_{S_3}\right|^2 > \left|\boldsymbol{h}_{S_4}\right|^2$. In this scenario, the nearest SU is positioned beyond the furthest PU, i.e. $\left|\boldsymbol{h}_{P_4}\right|^2 > \left|\boldsymbol{h}_{S_1}\right|^2$. The SUs can exploit the service of this CR network with the rates defined as $R_{S_1}, R_{S_2}, R_{S_3}$, and R_{S_4}.

In the CR network, the main idea is how to exploit all PUs' resources subject to satisfy an acceptable QoS. This is because in several cases, such as in the internet of things (IoT), many devices have been reserved resources in a network, while these rates are not exploited correctly i.e. each device may have a known limited rate depending on its operation.

Therefore, depending on this idea and before accomplishing the pairing of an SU with a PU, first, the users are tabulated subject to the required power for each one depending on its distance and the required rate. For each PU, PAF is evaluated and the required rate as expressed earlier inequations (4.1) and (4.5), respectively. Similarly, for each SU, the required PAF and the rate can be evaluated as:

$$R_S = \log_2\left(1 + \frac{p_t\, \alpha_S |\boldsymbol{h}_S|^2}{\sigma^2}\right) \tag{4.9}$$

and

$$\alpha_S = \frac{(2^{R_S} - 1)\sigma^2}{p_t\, |\boldsymbol{h}_S|^2}, \tag{4.10}$$

respectively. After these calculations, the pairing algorithm is used by selecting a PU that required a minimum PAF with an SU that required maximum PAF, and completing the pairing of all users depending on this idea, then the throughput for the elected pair is calculated as

$$R_{P_{elected}} = \log_2\left(1 + \frac{p_t\, \alpha_{P_{elected}} \left|\boldsymbol{h}_{\boldsymbol{p}\ \boldsymbol{elected}}\right|^2}{\sigma^2}\right) \tag{4.11}$$

$$R_{S_{elected}} = \log_2\left(1 + \frac{p_t\, (1 - \alpha_{P_{elected}}) \left|\boldsymbol{h}_{\boldsymbol{S}\ \boldsymbol{elected}}\right|^2}{p_t \alpha_{P_{elected}} \left|\boldsymbol{h}_{\boldsymbol{S}\ \boldsymbol{elected}}\right|^2 + \sigma^2}\right) \tag{4.12}$$

It is noteworthy that the priority for each PU in a pair is to be given the required power that satisfies the required throughput, then the rest of the power is given to the SU at that pair. After completing the first pair of this network, the same condition is applied to the rest users in the list to create four pairs each of which has a PU with an SU.

Table 4.2: The parameters of the proposed Algorithm 2 (4 PUs near the BS and another 4 SUs furthest from the BS).

Parameter	value	Name
B	1MHz	System Bandwidth
N	10^5bit	Number of bits per symbol
d_{p1},d_{p2} d_{p3} d_{p4}	(100,200,300,400)m	PUs distance from BS respectively
d_{s1},d_{s2} d_{s3} d_{s4}	(500,700,900,1100)m	(SU)s distance from BS respectively
β	4	Path loss exponent
r_{p1} ,r_{p2} ,r_{p3} ,r_{p4}	(2,1.75,1.85,1.5)bps/Hz	PUs target rates respectively
r_{s1} ,r_{s2} ,r_{s3} ,r_{s4}	(2.5,4,3.5,3)bps/Hz	SUs target rates respectively
p	0dBm to 40dBm	Transmitted power
N_{tx}	2	Number of antennas of MIMO at the BS
N_{rx}	2	Number of antennas of MIMO at the receiver
PU-SU	2	In each pair 1PU and 1SU
The simulation by MatLab code. Frequency non-selective Rayleigh fading channel is assumed in all transmission between the users and the BS, and the noise effect is taken into account by AWGN with zero mean and variance σ^2.		

Algorithm 2: Pairing Algorithm of MIMO-NOMA-CR (the 2nd scenario)
1: Input← channel gains of all users, PUs, and SUs $[\boldsymbol{h}_{\mathbf{P}_1}, \boldsymbol{h}_{\mathbf{P}_2}, \boldsymbol{h}_{\mathbf{P}_3}, \boldsymbol{h}_{\mathbf{P}_4}, \boldsymbol{h}_{\mathbf{S}_1}, \boldsymbol{h}_{\mathbf{S}_2}, \boldsymbol{h}_{\mathbf{S}_3}, \boldsymbol{h}_{\mathbf{S}_4}]$, 2: Input← selecting arrange of SNR to represent the available power at the BS. 3: Evaluate the target throughput of the PUs, R_P, via eq. (4.1). 4: Evaluate the required PAF for each PU, α_P, via eq. (4.5). 5: Evaluate the required PAF for each SU, α_S, via eq. (4.10). 6: list the results in steps 4 and 5 above in two matrices and sort the users in ascending order depending on the calculated PAFs. 7: Select the minimum PAF of the PUs' matrix and the maximum PAF of the SUs' matrix and pair those two users. 8: Repeat step 7 after removing the users in the elected pair from the above matrices for SUs and PUs till all users become in pairs. 9: For each elected pair, evaluate the throughput of the PU using (4.11) and for the SU using (4.12), and examine the outage probabilities for each user.

4.5 The Third Scenario

In this scenario, eight users, four SUs located near the BS with four PUs located far from the BS, are assumed. For modeling, this scenario, each of the four PUs, which are distributed in positions far from the BS, experiences a frequency non-selective Rayleigh fading channel which can be defined as $\boldsymbol{h}_{\boldsymbol{P}_{\boldsymbol{i}}} \sim CN(0, \sigma^2_{h_{p_i}})$, with $i \in \{1,2,3,4\}$, and $|\boldsymbol{h}_{\boldsymbol{P}_1}|^2 > |\boldsymbol{h}_{\boldsymbol{P}_2}|^2 > |\boldsymbol{h}_{\boldsymbol{P}_3}|^2 > |\boldsymbol{h}_{\boldsymbol{P}_4}|^2$. Moreover, the required rates of these four PUs are denoted as $R_{P_1}, R_{P_2}, R_{P_3,}$ and R_{P_4}. Regarding the SUs, the four SUs are assumed with the same channel distribution defined above for the PUs, i.e. $\boldsymbol{h}_{\boldsymbol{S}_{\boldsymbol{i}}} \sim CN\left(0, \sigma^2_{h_{S_i}}\right)$, and $|\boldsymbol{h}_{\boldsymbol{S}_1}|^2 > |\boldsymbol{h}_{\boldsymbol{S}_2}|^2 > |\boldsymbol{h}_{\boldsymbol{S}_3}|^2 > |\boldsymbol{h}_{\boldsymbol{S}_4}|^2$. In this scenario, the nearest PU is positioned beyond the furthest SU, i.e. $|\boldsymbol{h}_{\boldsymbol{S}_4}|^2 > |\boldsymbol{h}_{\boldsymbol{P}_1}|^2$. The SUs can exploit the service of this CR network with the rates defined as $R_{S_1}, R_{S_2}, R_{S_3,}$ and R_{S_4}. The pairing algorithm can be exploited again to couple a PU with an SU to create four pairs for the sake of obtaining optimum performance with the best QoS. In this scenario, the SU will be under the effect of high interference of the PU in each pair as explained earlier in NOMA theory. In the pairing algorithm for this scenario, the BS, which controls the CR network, examines the PUs to choose a PU that needs higher PAF to satisfy its target rate, and couples this chosen PU with an SU that requires lower power than other SUs. Therefore, pairing plays a significant optimization role to select the suitable pairs that satisfy the optimum performance. The service provider can utilize equations (4.1) and (4.5) to evaluate the rates and the PAFs for the PUs, respectively, while Eq. (4.9) and (4.10) can be used to calculate the rate and the PAF of each SU, respectively. Depending on this idea and for the locations assumed for the PUs and the SUs, the throughput for each elected SU and PU in a pair can be expressed as:

$$R_{S_{elected}} = \log_2\left(1 + \frac{p_t\, \alpha_{S_{elected}} |\boldsymbol{h}_{\boldsymbol{S}\ \boldsymbol{elected}}|^2}{\sigma^2}\right) \tag{4.13}$$

$$R_{P_{elected}} = \log_2\left(1 + \frac{p_t\, (1-\alpha_{S_{elected}})\, |\boldsymbol{h}_{\boldsymbol{P}\ \boldsymbol{elected}}|^2}{p_t\, \alpha_{S_{elected}} |\boldsymbol{h}_{\boldsymbol{P}\ \boldsymbol{elected}}|^2 + \sigma^2}\right) \tag{4.14}$$

For the MIMO-NOMA-CR network assumed in this scenario, the equation. (4.14) can be used to evaluate the required PAF of the PU in a pair, α_P, taking into account the required rate for this user. This can be expressed as:

$$2^{R_{P_{elected}}} - 1 \leq \frac{p_t\, \alpha_{P_{elected}} \left| \boldsymbol{h}_{\boldsymbol{P}\ \boldsymbol{elected}} \right|^2}{p_t (1 - \alpha_{P_{elected}}) \left| \boldsymbol{h}_{\boldsymbol{P}\ \boldsymbol{elected}} \right|^2 + \sigma^2} \tag{4.15}$$

where the chosen value of α_P in (15) refers to satisfying the SINR of the PU in a pair should be equal to or greater than the term on the left of the equation (4.15). After obtaining α_P, α_S represents the rest of the total power, i.e. $\alpha_S = 1 - \alpha_P$, which is given to the SU at that pair. This procedure is applied at each pair, and each pair of SU and PU share the service within the network unless any changes occur related to the required power and the throughput of all users in the coverage area of the BS.

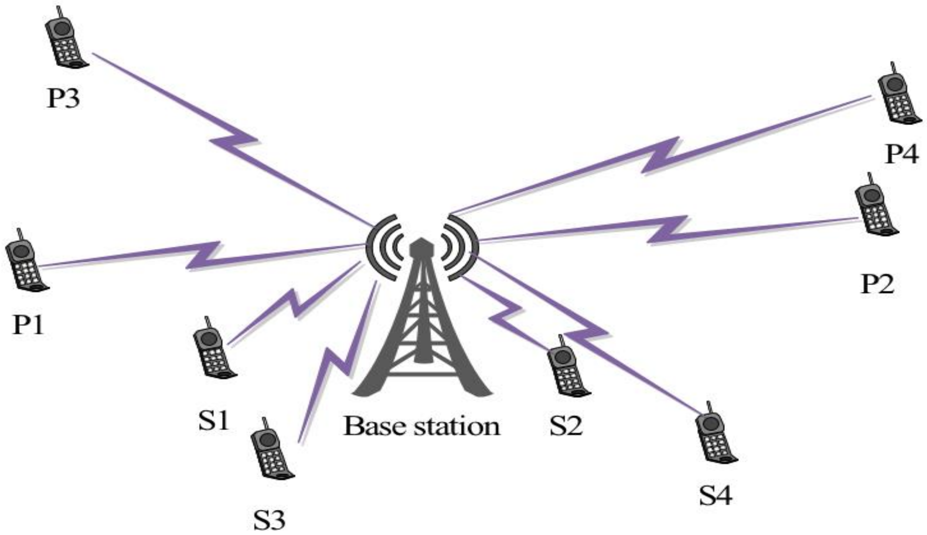

Fig. 4.3: Service provider to serve 4-PUs and 4-SUs for the 3rd scenario.

Table 4.3: The parameters of the proposed Algorithm 3 (4 SUs near the BS and 4 PUs are furthest from the BS).

Parameter	Value	Name
B	1MHz	System Bandwidth
N	10^5bit	Number of bits per symbol
d_{p1},d_{p2} d_{p3} d_{p4}	(500,700,900,1100)m	PUs distance from BS respectively
d_{s1},d_{s2} d_{s3} d_{s4}	(100,200,300,400)m	(SU)s distance from BS respectively
β	4	Path loss exponent
r_{p1} ,r_{p2} ,r_{p3} ,r_{p4}	(2,1.75,1.85,1.5)bps/Hz	PUs target rates respectively
r_{s1} ,r_{s2} ,r_{s3} ,r_{s4}	(2.5,4,3.5,3)bps/Hz	SUs target rates respectively
p	0dBm to 40dBm	Transmitted power
N_{tx}	2	Number of antennas of MIMO at the BS
N_{rx}	2	Number of antennas of MIMO at the receiver
PU-SU	2	In each pair 1PU and 1SU
The simulation by MatLab code. Frequency non-selective Rayleigh fading channel is assumed in all transmission between the users and the BS, and the noise effect is taken into account by assuming AWGN with zero mean and variance σ^2.		

Algorithm 3: Pairing Algorithm of MIMO-NOMA-CR (the 3rd scenario)
1: Input← channel gains of all users, PUs, and SUs. $[\boldsymbol{h}_{\mathbf{P}_1}, \boldsymbol{h}_{\mathbf{P}_2}, \boldsymbol{h}_{\mathbf{P}_3}, \boldsymbol{h}_{\mathbf{P}_4}, \boldsymbol{h}_{\mathbf{S}_1}, \boldsymbol{h}_{\mathbf{S}_2}, \boldsymbol{h}_{\mathbf{S}_3}, \boldsymbol{h}_{\mathbf{S}_4}]$. 2: Input← selecting arrange of SNR to represent the available power at the BS. 3: Evaluate the required PAF for each PU, α_P, via (4.5). 4: Evaluate the required PAF for each SU, α_S, via (4.10). 5: list the results in steps 3 and 4 above in two matrices and sort the users in ascending order depending on the calculated PAFs. 6: Select the maximum PAF of the PUs' matrix and the minimum PAF of the SUs' matrix and pair those two users. 7: Repeat step 6 after removing the users in the elected pair from the above matrices for SUs and PUs till all users become in pairs. 8: Generating multi-value for α_P depending on the channel coefficient and its target rate and this value must satisfy the condition equation (4.15). 9: For each elected pair, evaluate the throughput of the PU using (4.14) and for the SU using (4.13), and examine the outage probabilities for each user.

4.6 SIMULATION RESULTS AND DISCUSSIONS

In this section, the three scenarios considered in this chapter are simulated and the two performance metrics, which are the outage probability and the throughput, are evaluated using Matlab Programming. Each of the BS and the users are equipped with $N_{tx} = 2$ and $N_{rx} = 2$, and all the channels are assumed as frequency non-selective Rayleigh flat fading with a path-loss exponent of $\beta = 4$.

For the first scenario, four users are assumed, one of the four users that are nearest to the BS is the PU and the others are SUs. The three SUs are the furthest users from the BS than the PU as shown in Figure.4.1, with $d_1 = 800m\ d_2 = 700m, d_3 = 400m,$ and $d_4 = d_P = 300m$. Figure.4.4 shows the sum rate against a range of transmitted power in (dBm) for three cases, which are a traditional NOMA with single-input single-output (SISO), MIMO-NOMA, and MIMO-NOMA-CR with the 2×2 antennas at the transmitter and the receiver, as defined earlier in this section. The PAF for each user is as explained earlier in Section. As for the case of common NOMA using $K_1 = K_2 = K_3 = 0.75$, while with CR, the PAF required to satisfy the required rate of the PU is evaluated using Eq. (4.5), and the rest of the power is distributed among the SUs depending on their distance from the BS. For MIMO-NOMA-CR, and for comparison purposes, the arbitrary factors are assumed as $K_1 = K_2 = 0.75$.

It can be seen that MIMO with this number of antennas can improve the sum rate by more than 2 bits/sec/Hz. Moreover, using CR with this MIMO-NOMA reduces the achievable throughput due to allocating a high portion of the available power to the PU to satisfy its required rate, and user fairness is applied to the SUs only.

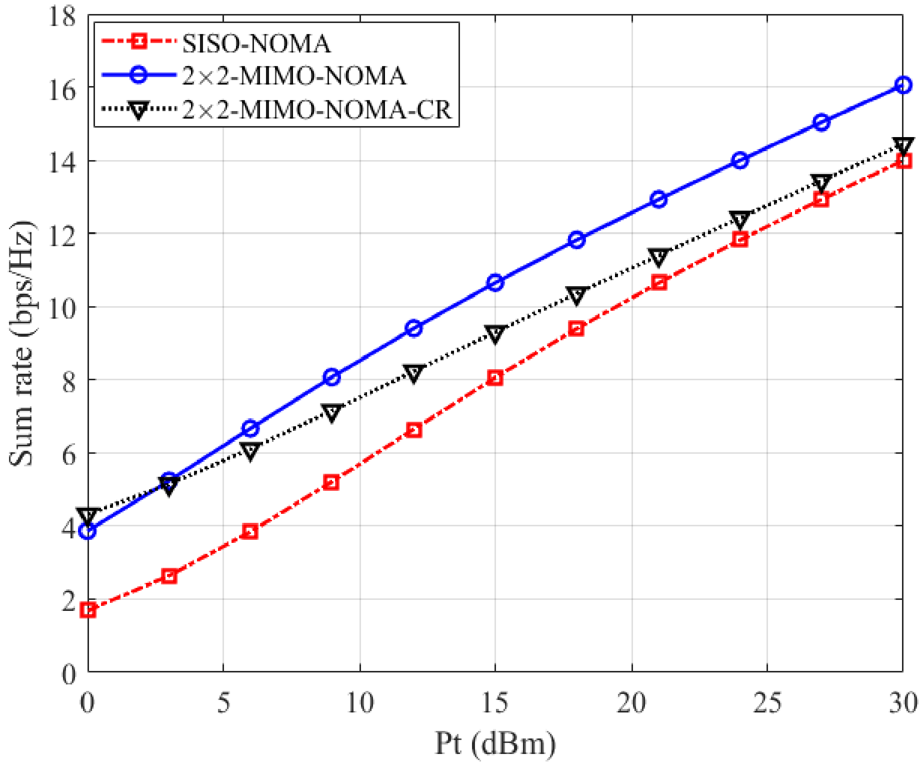

Fig. 4.4: Sum rate achieved for the 1st scenario, with three cases, SISO-NOMA, 2×2-MIMO-NOMA, and 2×2-MIMO-NOMA-CR with $K_i = 0.75$.

Figure 4.5 shows the 1st scenario's outage probability for the SUs, after applying CR to the traditional MIMO-NOMA, by assuming the required rates in bit-per-second (bps) as $R_{S_1} = 1$ bps, $R_{S_2} = 1.5$ bps, and $R_{S_3} = 2$ bps for SU1, SU2, and SU3, respectively, in the presence of one PU located near the BS with a required rate of $R_P = 2.5$ bps. The latter rate for the PU is used to evaluate its PAF, α_P, by using equation(5) as mentioned earlier. For comparison purposes, K_i is assumed equal to 0.75 which does not give optimum user fairness for the SUs.

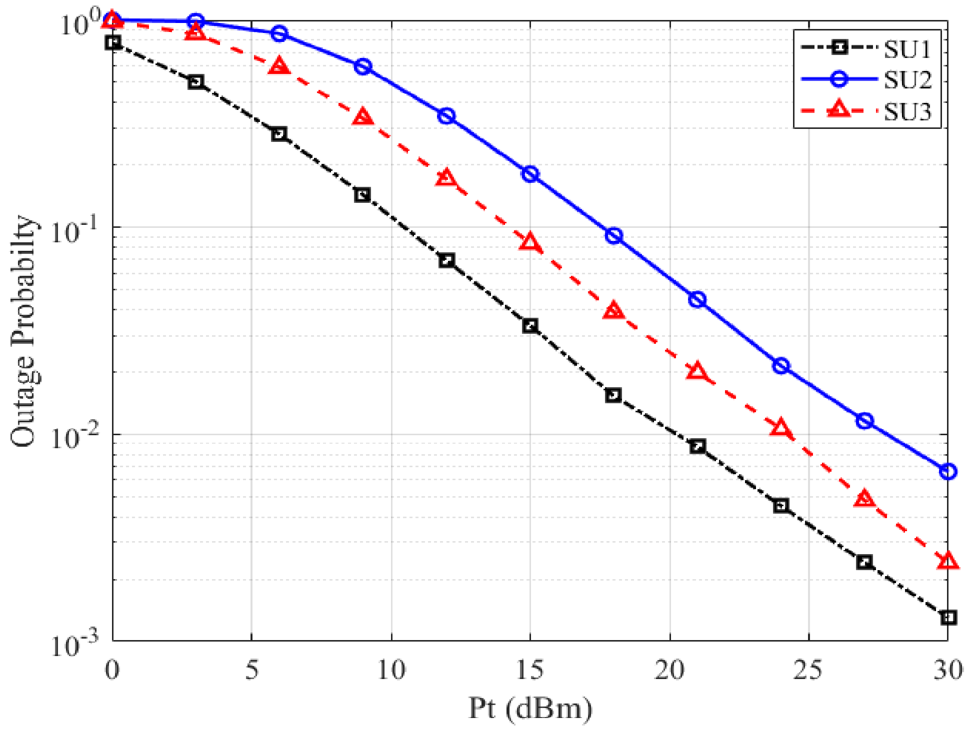

Fig. 4.5: Outage probability of the 1st scenario for 2×2*-MIMO-NOMA-CR with* $R_P = 2.5bps$ *with* $K_i = 0.75$.

It is worth mentioning that optimization methods, which are out of the scope of this thesis, can be applied from Equation (4.1) to (4.8) to evaluate the optimum PAF to ensure user fairness depending on the rate of each user. In this section, the trial-and-error technique is activated leading to obtain $K_1 = 0.6$, $K_2 = 0.85$ and $K_3 = 0.85$, which demonstrates a convergence for the outage probabilities for the three SUs as shown in Figure.4.6, which reveals some sort of user fairness. Additionally, in Figure 4.7, the outage probabilities of SU1 for the three cases considered in the 1st scenario are shown after applying the obtained values of K_i.

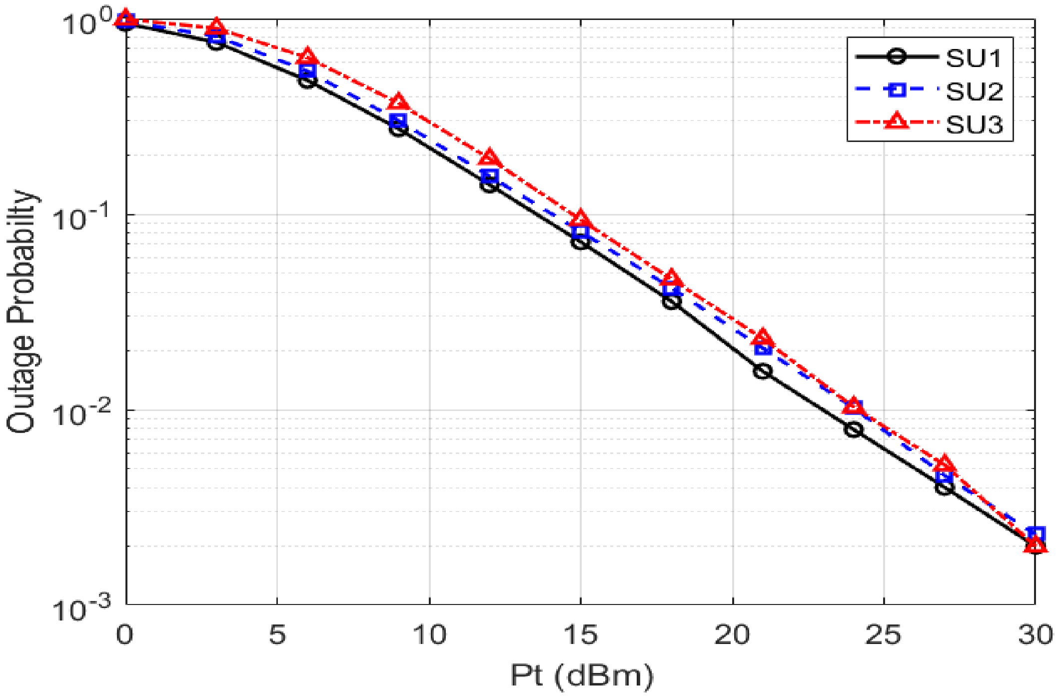

Fig. 4.6: Outage probabilities for the 1st scenario for 2×2*-MIMO-NOMA-CR with* $R_P = 2.5$*bps with* $K_1 = 0.6$, $K_2 = 0.85$ *and* $K_3 = 0.85$.

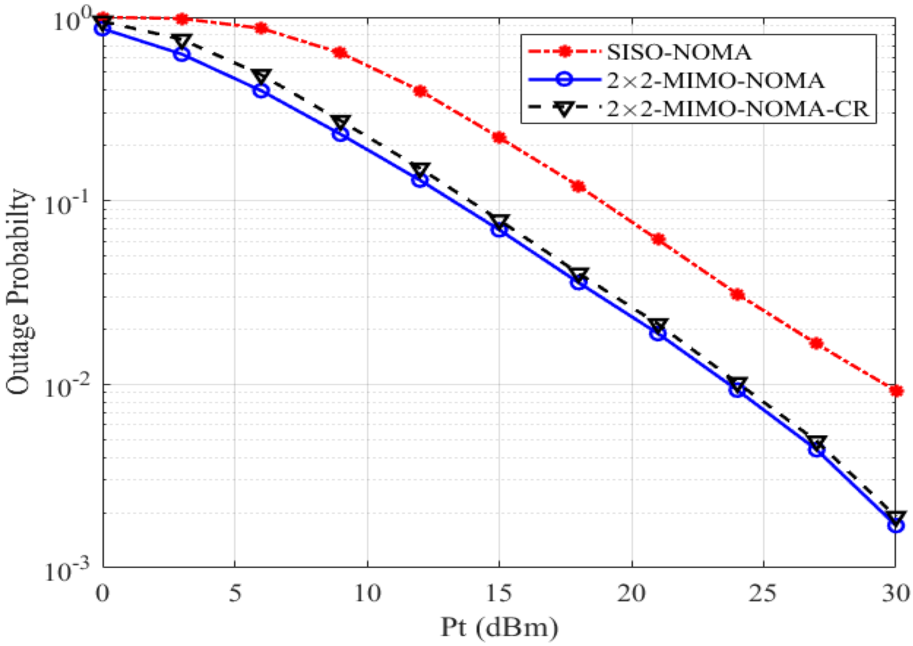

Fig. 4.7: Outage probabilities of SU1 for the 1st scenario, with three cases, SISO-NOMA, 2×2*-MIMO-NOMA, and* 2×2*-MIMO-NOMA-CR with* $K_i = [0.6, 0.85, 0.85]$*, note that SU2 and SU3 have exact-close performance for these* K_i.

For the second scenario, eight MIMO-NOMA-CR users are assumed, in which four PUs are considered near to the BS, while the SUs are distributed far from the BS. The distances of the PUs are equal to $d_{P1} = 100m, d_{P2} = 200m, d_{P3} = 300m$, and $d_{P4} = 400m$. While the distance of the SUs is equal to $d_{S1} = 500m, d_{S2} = 700m, d_{S3} = 900m$, and $d_{S4} = 1100m$. The same MIMO of 2×2 is assumed in this scenario with the same channel modeling considered in the first scenario. The pairing algorithm, as illustrated and explained in algorithm 2, is applied to the PUs and SUs for the sake of obtaining the optimum achievable rate and outage probabilities for all users. It is assumed that the required rates for the PUs are $R_{P1} = 2$ bps, $R_{P2} = 1.75$ bps, $R_{P3} = 1.85$ bps, and $R_{P4} = 1.5$ bps. While the SUs have minimum required rates defined as $R_{S1} = 2.5$ bps, $R_{S2} = 4$ bps, $R_{S3} = 3.5$ bps, and $R_{S4} = 3$ bps.

Figure 4.8 shows the outage probabilities of the four far SUs in the pairing MIMO-NOMA-CR network depending on the third scenario. It can be noticed that all the SUs, excludingSU_1, have the same outage probabilities which read at $P_t = 30\ dBm$ about 10^{-2}, while SU_1 needs an additional $4\ dBm$ to reach this outage probability. This reveals that the proposed algorithm for this scenario creates pairs depending on the given parameters, which are the required rate and the distance of each user from the BS, then allocates the PAFs to the PUs to enable them to obtain the required rates, and finally, the rest of the PAFs are allocated to the SUs. Depending on this idea, it is clear that the algorithm has successfully managed this process for most of the users in the coverage area, i.e. 7 users out of 8, and SU_1 is still served with the need for additional PAF to reach the same performance as the other SUs. Moreover, Figure.4.9 illustrates the obtained throughput over several values of the available power, which demonstrates the same observations mentioned above. It can be seen that all SUs can achieve rates exceeding 6 bps at $P_t = 30$ dBm to reach more than 10 bps at $P_t = 40$ dBm.

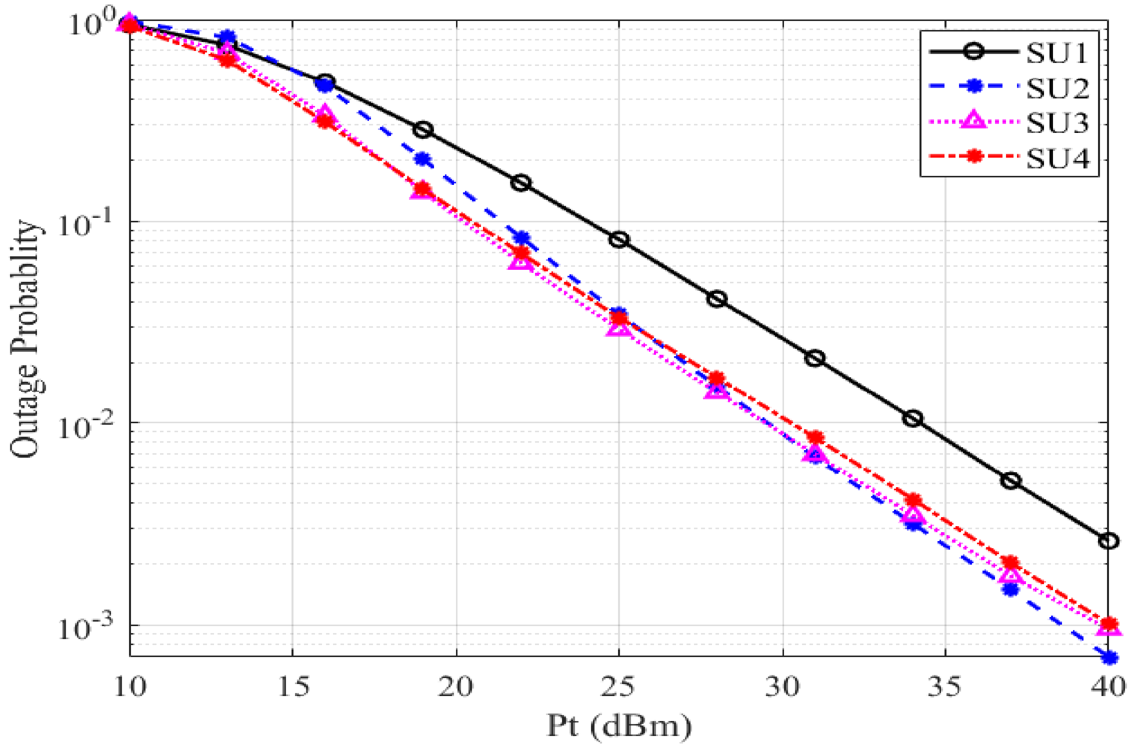

Fig. 4.8: Outage probabilities of all SUs for the 2nd scenario by assuming 2×2*-MIMO-NOMA-CR.*

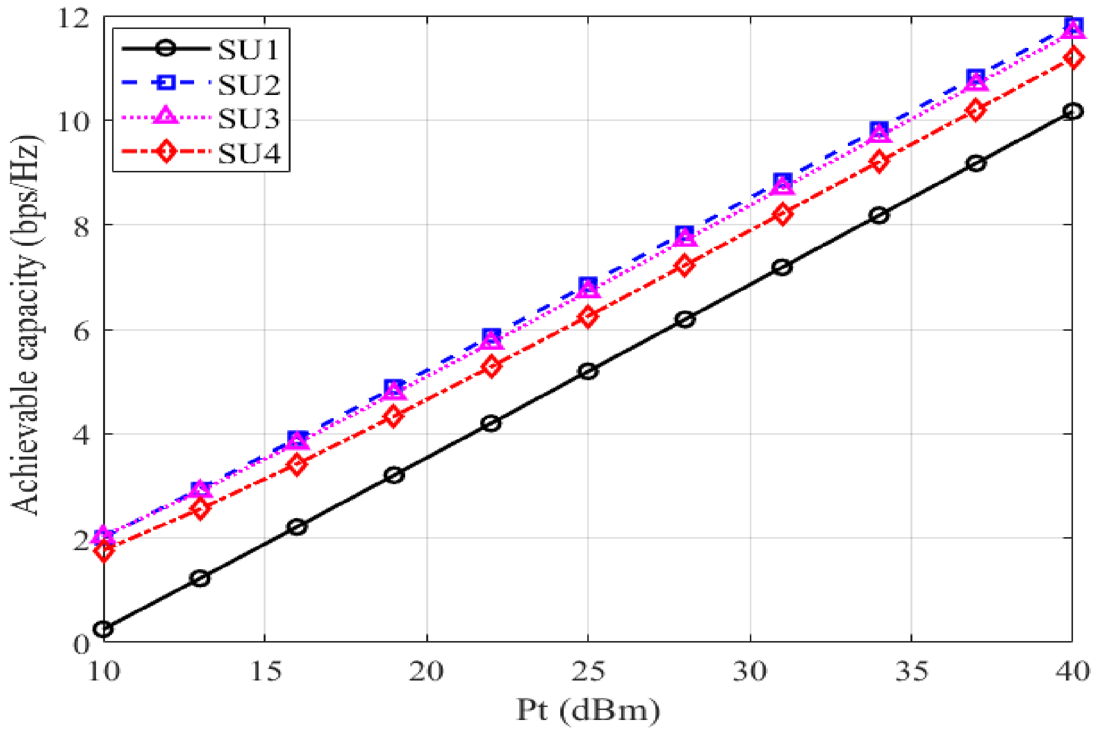

Fig. 4.9: 2×2*-MIMO-NOMA-CR achievable rates of all SUs for the 2nd scenario.*

In the third scenario, it has been assumed that the locations of the SUs and the PUs are exchanged, i.e. the distances assumed for the PUs in the second scenario are given to the SUs and vice versa. Moreover, it has been assumed that the required rates for all users are the same as in the second scenario. Figure.4.10 shows the outage probabilities for all the near SUs, which are paired with far PUs after applying the third algorithm. Again, the SUs and the PUs are paired depending on their distances and required rates. It can be seen from this figure that at $P_t = 30$ dBm, SU_2 and SU_3 almost keep their performance as the 2nd scenario, while SU_1 performance is enhanced with degradation of SU_4's performance. In Figure.4.11, the achievable rates for the SUs are obtained to demonstrate significant improvement of SU_1 at $P_t = 30$ dBm to reach about 10 bps, with slight degradation of the throughput for the other SUs compared to the 2nd scenario. This is because, after completing the paring, more PAF are allocated to the PUs to keep their target rates, as they have the priority to be served depending on the CR theory.

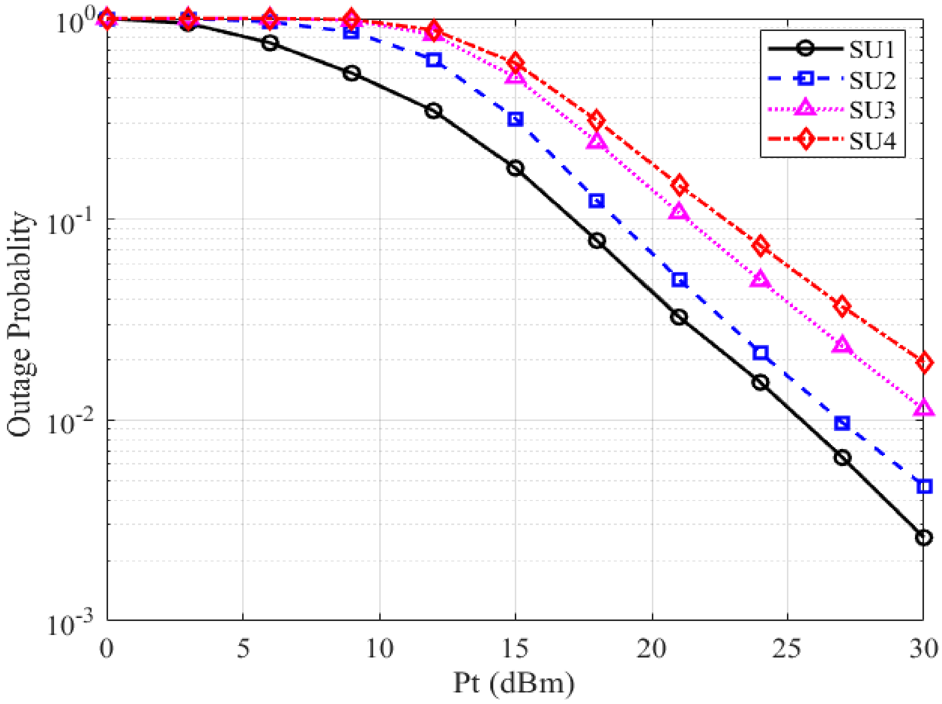

Fig. 4.10: Outage probabilities of all SUs for the 3rd scenario by assuming 2×2*-MIMO-NOMA-CR.*

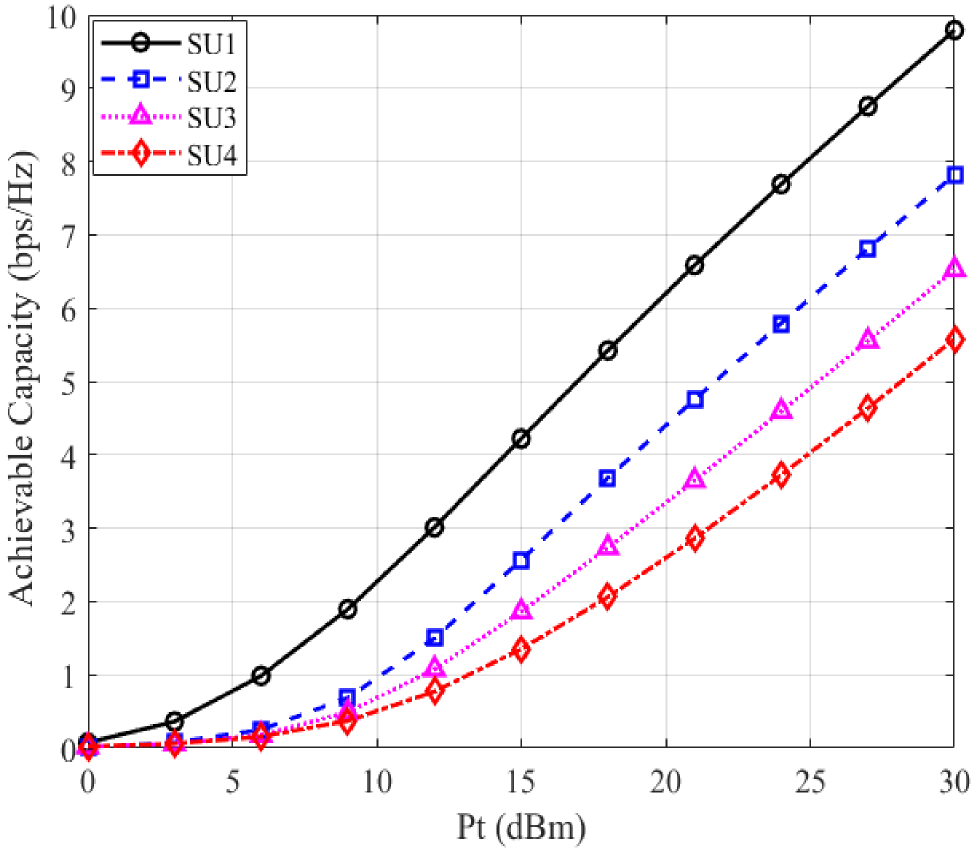

Fig. 4.11: 2 × 2-MIMO-NOMA-CR achievable rates of all SUs for the 3rd scenario.

CHAPTER FIVE

Conclusions and Future Works

5.1 Conclusions

In this thesis, CR-NOMA has been proposed to optimize spectrum utilization along with spectrum efficiency. CR has been merged with NOMA to enable secondary users to use the available spectrum without the need to achieve spectrum sensing to check the absence of the primary user, i.e. both users utilize the same frequency band simultaneously. Another technique used with CR-based NOMA is MIMO to increase the system throughput and during the simulation results by MatLab code, it has been concluded:

- Sharing the spectrum is subject to making the primary user obtain its required rate without any degradation in its performance. This has been achieved by allocating the primary user the suitable PAF in the downlink mode, while in the uplink mode, the pairing algorithm can be employed to choose a suitable secondary user in the coverage area so that its distance from the BS ensures obtaining the required rate for the primary user without any effect.
- The outage probability and the achievable throughput of the CR-NOMA for two paired users have been obtained via Monte Carlo simulation to reveal the success of the proposed system. The results showed outperforming the primary user on those two performance metrics against the secondary user in different scenarios.
- paring algorithm can play a significant role by choosing a suitable secondary user that utilizes the spectrum without any performance degradation from the primary user.
- Three scenarios were proposed for three different scenarios of CR based on MIMO-NOMA. For each case, the mathematical expressions for the

- PAF and the achievable capacity have been evaluated. Besides, the outage probabilities were obtained via Matlab simulations depending on the target rate of each user.
- The compassion of CR-MIMO-NOMA with traditional SISO-NOMA and MIMO-NOMA transmission models has been achieved in the first scenario. In this case, three SUs as CR users were assumed to be served in the presence of a single PU positioned near the service provider. The sum rate results reveal outperforming of the proposed scenario over the SISO-NOMA, with about two bits per sec to reach the throughput of the traditional MIMO-NOMA, since the proposed algorithms assumed allocating the PUs their required powers to achieve their target rates, which results in degradation on the performance of the CR-SUs, in which the SUs were assumed to share the residual available power.
- The 2nd and 3rd algorithms for MIMO-NOMA-CR have proposed to service four SUs in the presence of four PUs positioned near and far from the BS, respectively, in which the priority has been given to the PUs to achieve the target rates wherever they are located.
- By using the pairing algorithm each SU has been coupled with a PU that satisfies the optimum performance for both users, i.e. an SU with minimum required throughput has been paired with a PU that needed maximum target rate and vice versa.
- In 2nd and 3rd scenarios and by utilizing the pairing algorithm, it is important to select a suitable near user that needs low power with a far user that needs high power, i.e. distinguish gab energy between pairing users, the first thing is the interference effect of the weakest users on the other users will be low, and at weakest users, the SIC will reconstruct and cancel the strongest user perfectly.

- One of the key outcomes, that can be highlighted from comparing the 2nd and 3rd scenarios is CR-based-NOMA which can achieve better performance when the CR-SUs are positioned far from the BS, and the PUs are positioned near the BS. This is because, depending on the NOMA theory, the furthest user can obtain a higher portion of the available power in the traditional NOMA, without the need to apply SIC to cancel the interference of the near user.
- In our 2nd scenario, the near PUs have been given lower PAFs to satisfy their target rates, in addition to applying SIC to reduce the interference and enhance the performance, while the far SUs have been given higher PAFs which assist significantly in obtaining higher throughputs with acceptable outage probabilities.

5.2 Future Works

The performed work in this thesis employs MIMO-NOMA based on CR to improve the throughput and enhance the spectrum efficiency. However, some aspects, which are not included due to the limited time, can be taken into consideration and employed with the proposed systems and algorithms to enhance the entire performance. These aspects are listed below:

1. In-band full-duplex can be exploited with NOMA-CR to enhance the capacity of the proposed wireless system. The capacity can be duplicated if perfect and accurate self-interference cancellation is achieved.
2. The conventional MIMO used in this work, with a limited number of antennas, can be replaced with a massive MIMO. The latter can improve the throughput of the system significantly if the design ensures that all the created channels between the wireless devices are uncorrelated which leads to an increase in the diversity gain.

3. Cooperative communications via relays can be added to the proposed systems. This can be implemented by using amplify-and-forward (AF) relays for the sake of amplifying the signals, or decode-and-forward (DF) relays to reduce the error probability. This technique can be employed to tackle the high attenuation channels due to long distances between the users and the BS, or because of the obstacles.
4. More investigations can be achieved for the proposed system if different channel distributions are used such as Rician channels, frequency selective channels, millimeter wave, and Terahertz channels.
5. Channel coding as convolutional and turbo codes can be added to the systems to reduce the error probability and improve the outage probability.

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الخلاصـة

في هذه الرسالة ، يتم استخدام الوصول المتعدد غير المتعامد (NOMA) مع تقنيات مختلفة وسيناريوهات مختلفة على النحو التالي؛ أولاً، الراديو المعرفي (CR) المدمج مع تقنية ال NOMA تم اخذه بنظر الاعتبار عبر تردد قنوات رايلي المتلاشية غير انتقائية التردد حيث تم دمج التقنيتين من أجل تحسين أداء الاتصالات اللاسلكية متعددة المستخدمين (MU). علاوة على ذلك ، يمكن للراديو المعرفي و تقنية ال NOMA أن يحسنان بشكل كبير من استخدام الطيف وكفاءة الطيف، على التوالي، للجيل القادم من الاتصالات اللاسلكية. علاوة على ذلك، يمكن لـ NOMA تمكين ال CR من العمل دون الحاجة إلى تنفيذ استشعار الطيف كما هو الحال في ال CR التقليدي. يمكن تحقيق ذلك من خلال مشاركة القنوات المتاحة بين مختلف المستخدمين من خلال استخدام نفس نطاق التردد وفي نفس الوقت، ولكن مع عوامل مختلفة لتخصيص القدرة (PAF) في حيز القدرة. بالإضافة إلى ذلك ، تم اقتراح CR-NOMA في هذه الرسالة من خلال إعطاء المستخدم الأساسي الأولوية للتواصل مع المحطة الأساسية (BS) بمعدل الهدف المطلوب من الانتاجية (Throughput) دون أي تأثير على أدائه، بينما يمكن للمستخدم الثانوي استخدام الخدمة بالحد الأدنى المقبول من معدل انتاجيته وبوجود المستخدم الأساسي. يمكن تحقيق ذلك من خلال ترتيب PAF للتحكم في هذه العملية. تم النظر في سيناريوهات مختلفة لاثنين من المستخدمين، وأظهرت نتائج المحاكاة تفوق المستخدم الأساسي في مقابل المستخدم الثانوي في مقياسين للأداء وهما احتمالية الانقطاع ومعدل الانتاجية الممكن تحقيقه. ثانيًا، تم اقتراح تقنية NOMA القائمة على الراديو المعرفي ذات المدخلات المتعددة والمخرجات المتعددة (MIMO) من أجل تحسين الإنتاجية القابلة للتحقيق وإرضاء عدالة المستخدم. علاوة على ذلك، يتيح استخدام MIMO-NOMA لمستخدمي CR الخدمة في شبكة التغطية دون الحاجة إلى الاستشعار الطيفي. تم افتراض ثلاثة سيناريوهات في هذا الجزء من الرسالة للتحقيق في أداء كل مستخدم ثانوي بوجود مستخدمين أساسيين فرديين أو متعددين. تم اقتراح خوارزميات الاقتران وتطبيقها للحصول على الإنتاجية المثلى وباقل احتمالات الانقطاع، حيث يتم استخدام هذه الخوارزميات لتشكيل مجاميع تتكون كل مجموعة من مستخدمين فقط احدهما رئيسي والاخر ثانوي، اعتمادًا على تخصيص الطاقة المطلوبة لكل مستخدم، مع الأخذ في الاعتبار أن أي المستخدم الرئيسي له الأولوية للوصول إلى إنتاجيتة المطلوبة. بالاضافة الى ذلك، تم اشتقاق التعبيرات الرياضية لكل حالة لتقييم عامل تخصيص الطاقة المطلوب والإنتاجية التي يمكن تحقيقها لكل مستخدم. علاوة على ذلك ، تُظهر الخوارزميات المقترحة معدلات نجاح مرضية قابلة للتحقيق مع احتماليات انقطاع مقبولة لجميع المستخدمين.

إقرار لجنة المناقشة

نشهد بأننا أعضاء لجنة التقويم والمناقشة قد اطلعنا على هذه الرسالة الموسومة **(تصميم وتحقيق الاداء للراديو المعرفي القائم على الوصول المتعدد غير المتعامد (NOMA) للجيل القادم من الاتصالات اللاسلكية)** وناقشنا الطالب **(احمد عبد سعيد سلطان)** في محتوياتها وفيما له علاقة بها بتاريخ / /2022 وقد وجدناه جديراً بنيل شهادة الماجستير-علوم في اختصاص هندسة الاتصالات.

التوقيع:	التوقيع:
رئيس اللجنة:	عضو اللجنة:
التاريخ: / /2022	التاريخ: / /2022

التوقيع:	التوقيع:
عضو اللجنة:	عضو اللجنة(المشرف): أ.م.د.محمد عبدالرحمن
التاريخ: / /2022	التاريخ: / /2022

قرار مجلس الكلية

اجتمع مجلس كلية هندسة الالكترونيات بجلسته المنعقدة بتاريخ : / / 2022

وقرر المجلس منح الطالب شهادة الماجستير علوم في اختصاص هندسة الاتصالات.

التوقيع:	التوقيع:
مقرر المجلس:أ.م.د. صدقي بكر ذنون	رئيس مجلس الكلية: أ.د. خالد خليل محمد
التاريخ: / /2022	التاريخ: / /2022

إقرار المشرف

اشهد بان الرسالة الموسومة بـ **"تصميم وتحقيق الاداء للراديو المعرفي القائم على الوصول المتعدد غير المتعامد (NOMA) للجيل القادم من الاتصالات اللاسلكية"** تم اعدادها من قبل الطالب (احمد عبد سعيد سلطان) تحت اشرافي وهي جزء من متطلبات نيل شهادة الماجستير في هندسة الاتصالات.

التوقيع:
المشرف: أ.م.د. محمد عبدالرحمن احمد الحبار
التاريخ: / / 2021

إقرار المقيم اللغوي

اشهد باني قمت بمراجعة الرسالة الموسومة بـ **"تصميم وتحقيق الاداء للراديو المعرفي القائم على الوصول المتعدد غير المتعامد (NOMA) للجيل القادم من الاتصالات اللاسلكية"** من الناحية اللغوية وتصحيح ما ورد فيها من أخطاء لغوية وتعبيرية وبذلك أصبحت الرسالة مؤهلة للمناقشة بقدر تعلق الامر بسلامة الأسلوب وصحة التعبير.

التوقيع :
المقوم اللغوي:
التاريخ: / / 2022

إقرار رئيس لجنة الدراسات العليا

بناء على التوصيات المقدمة من قبل المشرف والمقوم اللغوي أرشح هذه الرسالة للمناقشة.

التوقيع:
الاسم: أ.م.د. محمود احمد محمود
التاريخ: / / 2022

إقرار رئيس القسم

بناء على التوصيات المقدمة من قبل المشرف والمقوم اللغوي ورئيس لجنة الدراسات العليا أرشح هذه الرسالة للمناقشة.

التوقيع:
الاسم: أ.م.د. محمود احمد محمود
التاريخ: / / 2022

وزارة التعليم العالي والبحث العلمي

جامعة نينوى

كلية هندسة الالكترونيات

قسم هندسة الاتصالات

تصميم وتحقيق الاداء للراديو المعرفي القائم على الوصول المتعدد غير المتعامد (NOMA) للجيل القادم من الاتصالات اللاسلكية

رسالة تقدم بها

احمد عبد سعيد سلطان

إلى

مجلس كلية هندسة الالكترونيات

جامعة نينوى

كجزء من متطلبات نيل شهادة الماجستير

في

هندسة الاتصالات

بإشراف

أ.م.د. محمد عبدالرحمن احمد الحبار

1444 هـ **2022م**

وزارة التعليم العالي والبحث العلمي

جامعة نينوى

كلية هندسة الالكترونيات

قسم هندسة الاتصالات

تصميم وتحقيق الاداء للراديو المعرفي القائم على الوصول المتعدد غير المتعامد (NOMA) للجيل القادم من الاتصالات اللاسلكية

احمد عبد سعيد سلطان

رسالة ماجستير علوم في هندسة الاتصالات

بإشراف

أ.م.د. محمد عبدالرحمن احمد الحبار

1444 هـ 2022 م